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Economics and energy use efficiency of alternative cropping strategies for the dark brown soil zone of Saskatchewan

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ECONOMICS AND ENERGY USE EFFICIENCY OF ALTERNATIVE CROPPING STRATEGIES FOR THE DARK BROWN SOIL ZONE OF SASKATCHEWAN

Final Report

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output, but for grain crops only the seed was harvested. In contrast to energy output and to net energy produced, energy use efficiency, measured as yield of grain plus forage produced per unit of energy input or as energy output/energy input ratio, were highest for the OI managed systems (501 kg of harvested production GJ^{-1} of energy input, and an energy output/energy input ratio of 8.85); lower but generally similar energy efficiency for the HI and RI input systems (377 kg GJ^{-1} and 6.79 ratio, respectively). Thus overall, OI/DAP was the most energy efficient cropping system, while RI/DLW and RI/DAG generally ranked lowest in energy use efficiency.

At 2007 input costs and prices for conventional and organically grown crops, average net returns and 12-yr net present values were higher for organic than non-organic treatments, with the OI/DLW system being most profitable ($234 ha^{-1} yr^{-1} and $1959 ha^{-1}, respectively). Net returns averaged about 10% less for OI/DAG compared to the best system, and about 21% less for HI/DAG and RI/DAG (the best non-organic systems). The DLW treatments, with the inclusion of summer fallow or legume green manure partial-fallow once every 3 years, produced the highest net returns in drought years, while the more intensively cropped DAG treatments performed best in years with higher growing season precipitation. The DAP treatments were not economically competitive with the other treatments, often producing economic losses. The relative profitability of the organic systems was highly dependent on the existence of organic price premiums. When price premiums for organic crops were reduced to less than 70% of current levels, the organic treatments were less profitable than the comparable non-organic treatments. The organic treatments also experienced significantly lower (and often negative) net returns compared to the non-organic systems during completion of the 3-yr organic certification period. We estimated that it required 5 to 7 years after completion of certification for the organic systems to breakeven with the non-organic treatments. Thereafter the organic systems produced consistently higher net earnings. Production costs averaged 16% lower with OI compared to HI management, but we found little difference in total costs between the respective HI and RI treatments. The savings in expenditures for inorganic fertilizers and pesticides with organic

management more than offset the higher costs for seed, organic certification and inspection fees, and machine overhead. In contrast, the savings in expenditures for labor, fuel, repairs, and machine overhead were largely offset by higher expenditures for seed, fertilizers, and herbicides with RI compared to HI management. The organic systems displayed lower income variability than the non-organic systems, with OI/DLW preferred by risk averse producers who do not subscribe to all-risk crop insurance, and with the OI/DLW and OI/DAG treatments preferred by low and medium risk averse producers when having the added protection from the Canada/Saskatchewan all-risk crop insurance program. Among the non-organic treatments, producers with low risk aversion and who subscribe to all-risk crop insurance would choose the HI/DAG or RI/DAG systems, while those with moderate risk aversion would choose HI/DAG or HI/DLW, and those with high risk aversion would choose HI/DLW. Although our findings are encouraging with respect to non-renewable energy use efficiency and the economics of adopting alternative land use practices in this region, they raise a number of important practical concerns and environmental issues that also require consideration.

PART I

Non-Renewable Energy Use and Energy Use Efficiency

BACKGROUND AND OBJECTIVES

Rising energy costs, together with growing concerns about greenhouse gas emissions and the need to protect soil and water quality, are causing producers throughout the northern Great Plains to question the merits of high input agricultural production systems (Smith et al. 2004; Hoeppner et al. 2005; Pimentel et al. 2005). In response, producers have been moving gradually away from monoculture cereal rotations that rely on frequent summer fallowing, high rates of inorganic fertilizers, and intensive use of mechanical tillage, to extended and diversified crop rotations that include legume crops and use reduced- and zero-tillage practices (Smolik et al. 1995; Campbell et al. 2002; Zentner et al. 2002). At the same time, other producers have become increasingly interested in employing low-input and organic management methods of crop production (Entz et al. 2001; Smith et al. 2004; Pimentel et al. 2005). These newer or alternative cropping systems may offer opportunities for producers to reduce their reliance on non-renewable energy inputs and/or improve the overall energy use efficiency of their production systems (Coxworth et al. 1996; Gill et al. 2001), and thereby contribute positively to reducing greenhouse gas emissions and to enhancing the long-term environmental sustainability of the agricultural industry (Neitzert et al 1999; Gregory et al. 2005; Pimental et al. 2005).

Energy expended on crop production occurs in direct form through the burning of fossil fuels to power machinery for tillage, cultural operations, drying of crops, heating farm buildings, and transporting farm products. It also occurs indirectly through the combustion of fossil-based energy used in the manufacture and repair of farm machinery, and in the manufacture, packaging, and transport of crop inputs such as fertilizers and pesticides (Janzen et al. 1999). On the Canadian Prairies, energy expended in producing spring wheat (*Triticum aestivum* L.) with traditional high-input production methods increased more than 3-fold between 1948 and 1981 (Hopper 1984). More recently, Weseen et al. (1999) reported that energy use on prairie farms increased a further 28% between 1981 and 1996. This continued growth in non-renewable energy use is the result of increasing farm mechanization and specialization, and the expanded

use of fertilizers, herbicides, electricity, and other inputs designed to replace labor, raise productivity, substitute for declining soil fertility, and reduce the vagaries associated with the biological and environmental processes determining crop yields (Hirst 1974; Gayton 1982; Weseen et al. 1999).

In the subhumid Parkland region of the Canadian Prairies, Zentner et al. (2004) compared non-renewable energy inputs and energy use efficiency of monoculture cereal, cereal-oilseed, and cereal-oilseed-pulse rotations, each four years in length and each managed using zero, minimum and conventional tillage practices. They reported total energy use over a 12-yr period was largely unaffected by tillage method, but that it differed significantly by crop rotation. Although use of minimum and zero tillage practices provided significant energy savings in the form of fuel and machinery, these savings were largely offset by increased energy expended on pesticides and N fertilizers. Overall, energy requirements were lowest for the monoculture cereal rotation that included fallow once every 4 years, intermediate for the rotation that included a pulse crop, and highest for the cereal-oilseed rotation. By substituting a grain-legume for a cereal crop in the rotation, Zentner et al. (2004) reported an energy saving of about 13%, reflecting the lower N fertilizer requirements of legumes due to their ability to biologically fix N and the lower N fertilizer requirements of the subsequent cereal crop. They also reported that use of minimum and zero tillage management enhanced energy use efficiency (compared to conventional tillage) for the two mixed rotations, but not for the monoculture cereal rotation. This was because of higher grain yields obtained from improved soil moisture reserves with reduced tillage practices and other rotational benefits such as enhanced soil nutrient reserves and reduced crop pests that often accompany use of mixed cropping systems (Lafond et al. 1992; Gan et al. 2003; Fernandez and Zentner 2005). Results of other North American studies that compared the energetics of reduced and conventional tillage methods have generally confirmed these findings (Lockeretz 1983; Smolik et al. 1995; Zentner et al. 1998; Gill et al. 2001), or have reported modest to moderate reductions in energy use with conservation tillage. This was particularly true in regions

that have traditionally relied on the chisel plow or moldboard plow for primary tillage (McKyes et al. 1986; Clements et al. 1995; Swanton et al. 1996; Nagy et al. 2000; Gregory et al. 2005). In other parts of the world, use of minimum and zero tillage practices have also been shown to provide significant energy savings and/or improvements in energy use efficiency (Borin et al. 1997; Ugalde et al. 2007), while also contributing positively to other sustainability traits such as increased soil carbon storage, reduced nitrous oxide emissions, and enhanced biodiversity (Janzen et al. 1998; Fairweather and Campbell 2001; Gregory et al. 2005; Pimental et al. 2005).

Studies comparing conventional and organic production systems have generally reported significant energy savings with organic management. For example, in the Parkland region of the Canadian Prairies Hoeppner et al. (2005) compared a cereal-oilseed-pulse rotation and a cereal-oilseed-legume forage rotation, each managed using conventional and organic practices. They reported an energy savings of about 50% with organic over conventional management, and about a 40% energy savings with an integrated grain-forage rotation compared to the grains-only rotation. However, energy output for both rotations averaged 30% lower with organic management because of lower crop yields. Nonetheless, energy use efficiency was reported highest for the integrated grain-forage rotation with organic management. In Pennsylvania, Pimentel et al. (2005) compared energy use of a conventional corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation with an organically managed legume green manure-cereal-oilseed rotation. They too reported that the latter cropping system required 32% less energy and was more energy efficient than the conventionally managed crop rotation. Energy studies comparing conventional and organic or low-input farming systems in other parts of Canada (Clements et al. 1995), the USA (Clancy et al. 1993; Gregory et al. 2005), and Europe (Dalgaard et al. 2001; Haas et al. 2001) have reported similar findings.

The objective of this study was to determine and compare non-renewable energy inputs, energy output, and energy use efficiency of nine cropping systems, representing three methods of input management (high, reduced, and organic) and three levels of cropping diversity (low

cropping diversity and intensity, diversified cropping using annual grains, and diversified cropping using annual grains and perennial forages), over a 12-year period (1996-2007) for the semiarid Dark Brown soil zone (Typic Boroll) of the Canadian Prairies.

MATERIALS AND METHODS

Experimental data

The design and methods for the field experiment have been described previously (Brandt et al. 2003; Ulrich et al. 2003); thus only a summary of aspects necessary for an understanding of this study are presented.

The experiment was established in 1994 on gently sloping land (1 to 3%) at the Agriculture and Agri-Food Canada Research Farm at Scott, Saskatchewan (52° 22′ N; 108° 50′ W; elevation 713 m). The soil is a Dark Brown Chernozemic (Typic Boroll) developed from modified glacial till (Clayton and Ellis 1952), with a loam texture and surface pH in water paste of 5.4 to 5.9. The area had been cultivated for about 90 years to a cereal-fallow or cereal-cereal-fallow rotation with limited fertilization. An extensive site characterization was conducted in 1994 to identify inherent soil and biological properties and to create a baseline from which temporal changes in these properties could be measured (Selles et al. 1999). The site was uniformly cropped to barley (*Hordeum vulgare* L.) in 1994 to reduce residual effects.

Nine cropping systems, each six years in length, were established in 1995 consisting of three methods of input management and three levels of cropping diversity (Table 1). The input treatments were: [high (HI, which uses mechanical tillage for weed control on fallow areas and for seedbed preparation together with recommended rates of pesticides and fertilizers as required); reduced (RI, which uses conservation tillage together with integrated pest and nutrient management and higher seeding rate practices to enhance soil protection and reduce use of pesticides and fuel); and organic (OI, which uses organic management methods including mechanical tillage, non-chemical pest control, legume green manure, selected application of compost, higher seeding rates, and later seeding dates)]. The crop diversity treatments were: a

Table 1. Summary of cropping system treatments

Input level[1]	Crop diversity	Crop sequence[2]
High	DLW (low diversity and intensity of annual grains)	F_T-W-W-F_T-C-W
Reduced		L_{GM}-W-W-F_C-C-W
Organic		L_{GM}-W-W-L_{GM}-C^3-W
High	DAG (diversified using annual grams)	C-R-P-B_M-F_X-W
Reduced		C-R-P-B_M-F_X-W
Organic		L_{GM}-W-P-B_M/S_C-S_{CGM}-C^3
High	DAP (diversified using annual grains and perennial forages)	C-W-B_F-O/B_B&A^4-H-H
Reduced		C-W-B_F-O/B_B&A^4-H-H
Organic		C^3-W-B_F-O/B_B&A^4-H-H

[1] High input uses recommended rates of pesticides and fertilizers as required, reduced input uses integrated pest and nutrient management and higher seeding rate practices designed to enhance soil protection and reduce use of pesticides and fuel; and organic input uses organic management methods including non-chemical pest control, legume green manure, selected application of compost, higher seeding rates, and later seeding dates.

[2] F_T = tillage fallow, W = spring wheat, C = canola (*Brassica. rapa* L. or *B. napus* L.), L_{GM} = lentil (*Lens culinaris* Medikus) green manure, F_C = chemical fallow, P = field pea (*Pisum sativum* L.), B_M = malt barley, B_F = feed barley, S_C = sweet clover (*Melilotus officinalis* L.), S_{CGM} = sweet clover green manure, R = fall rye (*Secale cereale* L.), F_X = flax (*Linum usitatissimum* L.), O = oat (*Avena sativa* L.), B_B&A = bromegrass (*Bromus inermis* Leyss.)-alfalfa (*Medicago sativa* L.), and H = hay.

[3] Mustard (*B. juncea* L.) replaced canola in these organic systems beginning in 2001.

[4] The oat underseeded to bromegrass-alflafa was replaced with alfalfa alone beginning in 2002.

fallow-based rotation with low cropping diversity (DLW); a diversified rotation using cereal, oilseed, and pulse grains (DAG); and a diversified rotation using annual grains and perennial forages (DAP)].

The experiment used a split-split-plot design with input level as main-plots, cropping diversity as sub-plots, and crop or rotation phase as sub-sub-plots. Main plots were 1.08 ha, sub plots 0.3 ha, and crop phase plots 0.05 ha. All phases of each rotation were present every year and each rotation was cycled on its assigned plots. Each treatment was replicated four times.

Available soil N was determined for the 0-60 cm depth on samples taken in late October of each year, and gravimetric soil moisture was determined to 90 cm depth before seeding.

For the HI and OI treatments, tillage using a cultivator equipped with sweeps and mounted harrow was typically used to prepare the seedbed and to control emerging weeds prior to planting, while for the RI treatments glyphosate was applied prior to planting. All crops were planted using selected cultivars based on their suitability to the area, with the same cultivars used with all input and diversity treatments for a full 6-yr cycle. Seeding rates for most crops were typically higher for the OI and RI treatments (Table 2). The seed for the OI and RI treatments was treated with *Penicillium bilaii*, while pulse, green manure lentil, and alfalfa seed was treated with appropriate *rhizobium* inoculants for all treatments. Non-organic wheat, barley, and pea seed was treated with fungicide, while non-organic canola seed was treated with fungicide and insecticide. All plots were seeded with a disc drill with the exception of green manure lentil which was seeded with a hoe drill. Planting of crops for the HI and RI treatments was generally earlier than for OI treatments to permit improved control of weeds prior to sowing the latter treatments.

Fertilizer N (Table 2) and P were applied to non-organic crops based on soil test recommendations guidelines from the Saskatchewan Soil Testing Laboratory (1990) for each crop. For the HI treatments, the same fertilizer rates were applied to all replicates based on the average soil test level of plots for that crop-phase and treatment; for the RI treatments, the

Table 2. Average seed and fertilizer N rates (kg ha^{-1}) for input treatments (1996-2007)

	Seed rates[1]			Fertilizer N rates	
Crop	**High**	**Reduced**	**Organic**	**High**	**Reduced**
Alfalfa	7	7	7	-	-
Barley	75	112	112	31	31
Barley (underseeded)	-	-	84	-	-
Brome/Alfalfa	18	18	18	5	5
Canola (fallow or green manure)	6	8	8	19	26
Canola (stubble)	6	7	8	34	36
Flax	38	60	-	27	26
Lentil green manure	-	45	45	-	-
Mustard	-	-	7	-	-
Oat (underseeded)	37	37	37	19	16
Oat/Pea	173	173	173	-	-
Pea	201	266	254	10	8
Rye	82	118	-	41	41
Sweet Clover green manure	-	-	14	-	-
Wheat (fallow or green manure)	90	135	135	14	26
Wheat (stubble)	90	135	135	41	45

[1] Certified seed used in all cases.

fertilizer rates varied across replicates based on soil test values for each individual plot and crop type. The N was mid-row banded, while P was placed near the seed at an average rate of 16 kg P ha^{-1} for all non-organic annual crops. At the end of each 6-yr cycle, compost was applied to the RI/DAP and OI/DAP systems to replace the N that would be available had the forage and barley grown in these systems been fed to feeder cattle and the manure spread back on the land. The compost was applied and soil incorporated with tillage between the last forage phase and the subsequent grain phase.

Non-organic annual crops received in-crop herbicides as required for weed control based on plot surveys of weed populations; RI treatments received herbicides only if weed populations exceeded defined threshold values (Ulrich et al. 2003). Organically grown cereals and pea typically received post-seeding harrowing for weed control. Weeds on conventional fallow plots were controlled with tillage using a heavy-duty cultivator with sweeps and mounted harrow. Fallow plots for the RI systems relied on herbicides alone for weed control.

Grain yields were determined at crop maturity by direct harvesting a 1.2 m x 40 m area per plot using a small plot combine. Forage yield was determined on a 1.0 m x 40 m area per plot at the soft dough stage of oat and 10% bloom of alfalfa.

Growing season (1 May to 31 August) rainfall, temperature, and other weather parameters were recorded at the test site using an automated weather station and datalogger.

Energy Analysis

Process analysis (Fluck and Baird 1980) was used to assess the energy performance of the cropping systems. This involves identifying all direct and indirect non-renewable energy going into the manufacture, formulation, packaging, distribution, transportation, maintenance and application of all inputs used in production, and the energy content of all products removed from the soil for each cropping system. Spreadsheet programs were developed to compute annual total and unit energy inputs, level of gross energy output, and net energy balance or energy use efficiency (i.e., gross energy output minus energy input, harvested production per unit of energy

input, and energy output/energy input ratio), and annual variability in energy performance of each cropping system.

A 907 ha representative farm, with a typical complement of equipment for each cropping system, was used to extrapolate the research plot data to a farm-level basis. The physical quantities of inputs used were converted to energy values using appropriate and the most recent energy coefficients taken from the literature and adjusted for manufacturing technology improvements as described by Nagy (1999, 2000) (Table 3). Recommended depths of tillage (where appropriate) and travel speeds were assumed for all field operations (Table 4). Energy coefficients for products produced were taken as gross energy values as determined by laboratory bomb calorimeter testing of representative samples taken from the field study (Table 5). This method was employed to enable a standard means of comparing energy output since no single end-user of all crops or products was evident (i.e., not all crops were destined for consumption by humans or by the same type of animal). Therefore, the resulting gross energy output values for this study are higher than those reported in studies that have used metabolizable energy for humans as the measure of energy output (Zentner et al. 1989). For instance, the gross energy coefficient used for wheat in this study was 16.93 MJ kg^{-1} compared to 13.8 MJ kg^{-1} based on metabolizable energy content for human consumption.

Seed energy reflects the amount of non-renewable energy going into the production of the seed grains as reported by Nagy (1999). Energy associated with human labor was not included in the analysis because it was shown in earlier studies to account for less than 0.2% of total energy input for most cropping systems (Zentner et al. 1984). Further, no allowance was made for energy removed from the soil in the form of plant nutrients, energy captured in terms of soil organic matter increases or losses, nor for that which was captured directly from the sun by the growing plants. The analysis also excludes heating and electrical energy used for the home and farm buildings, and energy associated with transportation and subsequent processing of the grains beyond the point of initial sale (i.e., beyond delivery to a local elevator or processing facility).

Table 3. Energy coefficients for farm inputs

Input	Energy content (MJ)	Unit
Herbicides		
2,4-D amine	71.5	kg a.i.
2,4-D ester	175.9	kg a.i.
2,4-DB	289.0	kg a.i.
Bromoxynil	324.7	kg a.i.
Bromoxynil and MCPA ester (1:1)	244.6	kg a.i.
Clethodim	230.9	kg a.i.
Clodinafop-propargyl	217.1	kg a.i.
Clopyralid	113.5	kg a.i.
Dicamba	245.3	kg a.i.
Dicamba and 2,4-D amine and Mecoprop (22:59:16)	104.5	kg a.i.
Diquat	346.8	kg a.i.
Ethalfluralin	224.8	kg a.i.
Ethametsulfron methyl	246.3	kg a.i.
Flamprop-methyl	224.8	kg a.i.
Fluroxypr and 2,4-D ester (15:47)	239.5	kg a.i.
Glufosinate ammonium	265.4	kg a.i.
Glyphosate	373.0	kg a.i.
Glyphosate and Dicamba (11:5)	268.6	kg a.i.
Imazamox and Imazethapr (1:1)	152.1	kg a.i.
MCPA amine	105.9	kg a.i.
MCPA sodium salt	396.7	kg a.i.
MCPB and MCPA amine (15:1)	87.0	kg a.i.
Metribuzin	146.0	kg a.i.
Metribuzin and MCPA sodium salt (7:1)	209.5	kg a.i.
Quizalofop-p-ethyl	280.8	kg a.i.
Sethoxydim	224.8	kg a.i.
Surfactant	201.0	L
Thifensulfuron methyl and Tribnuron methyl (2:1)	246.3	kg a.i.
Tralkoxydim	229.0	kg a.i.
Triallate	168.6	kg a.i.
Insecticides		
Carbaryl	168.5	kg a.i.
Chlorpyrifos	245.0	kg a.i.
Cyhalpthrin-lambda	152.8	kg a.i.
Deltamethrin	217.0	kg a.i.
Fungicides		
Propiconazole	400.0	kg a.i.
Seed treatments		
Carbathiin and Lindane (12:11)	120.2	kg a.i.
Carbathiin and Thiram and Lindane (9:18:136)	116.1	kg a.i.
Inoculant	33.0	kg
Penicillium balaii	101.6	kg
Thiabendazole and Thiram and Lindane (1:3:25)	116.7	kg a.i.

Fertilizers		
N	70.88	kg
P_2O_5	9.53	kg
Compost	82.20	t
Fuel and oil		
Gasoline	34.8	L
Diesel	39.0	L
Lubricants	43.8	L

Source: Nagy (1999) and Nagy (2000).

Table 4. Energy coefficients for field operations and farm buildings

Machine/building operation	Fuel, oil, and lubrication	Manufacture and repair of machines or buildings
	(MJ ha^{-1})	(MJ ha^{-1})
Combine	261.0[1]	42.7
Transport grain (field to yard)	58.8[1]	19.9
Transport grain (yard to elevator)	99.9[1]	39.3
Transport seed & fertilizer (yard to field)	5.5	2.1
Round baling	71.8[1]	84.7
Haul bales (field to yard)	98.7[1]	41.7
Haul water	23.0	3.5
Broadcast seed	85.9	4.9
Double disk press drill	116.1	34.3
Field cultivator	106.0	13.9
Harrow	48.5	10.0
Mower conditioner	167.1	28.2
Hoe press drill	178.4	40.8
Packing	57.5	14.8
Harrow packer	76.6	19.7
Harrow packer & harrow[2]	107.2	27.6
Heavy duty cultivator	183.4	21.2
Heavy duty cultivator & harrow packer[2]	256.8	29.7
Heavy duty cultivator with tine harrows	193.0	22.3
Heavy duty cultivator with tine harrows & harrow packer[2]	270.2	31.2
Heavy duty cultivator with trailing rodweeder	193.0	22.3
Manure (compost) application	219.6	64.1
Medium duty cultivator	165.1	19.3
Medium duty cultivator with tine harrows	173.8	20.3
Medium duty cultivator with trailing rod and harrows	182.5	21.3
Medium duty cultivator with spikes	165.1	19.3
Land roller	123.6	37.0
Rodweeder	93.2	23.1
Rotary harrow	48.5	10.0
Swath	102.0	23.7
Spray	35.2	12.6
Pickup truck (farm business)	99.3	31.0
Grain storage	-	47.0
Shop and machine storage	-	5.7

Source: Nagy (1999) and Nagy (2000).

[1] Yield dependent. Shown for a yield of 2000 kg ha^{-1}.

[2] Relects a combined field operation.

Table 5. Energy content of grain and forage crops[1]

Crop	Energy (MJ kg^{-1})
Barley	16.86
Canola	27.33
Flax	26.03
Grass-legume hay	14.42
Mustard	26.23
Oat hay	14.42
Oat /pea hay	15.08
Pea	16.65
Rye	16.64
Wheat	16.93

[1] Determined by bomb calorimeter analysis of representative samples.

The energy performance results were expressed on a per hectare basis for the complete cropping systems, which includes the energy inputs and outputs for all cropped and fallowed portions of each treatment. Data for the initial year of the experiment (1995) were excluded because not all crops were yet in proper sequence, and thus their performance would not be reflective of true treatment effects. All data were initially subjected to analysis of variance on an annual basis for split-split plot designs using Proc Mixed, with the residuals tested for normality with Proc Univariate of SAS (SAS Inst. Inc., 2006a). The presence of an excess of zeros in the data created an overdispersion problem, hence the data were transformed using a gamma distribution (Littell et al. 2006) and subsequently analyzed using PROC GLIMMIX of SAS Version 9.1 (SAS Inst. inc., 2006b). Input and diversity levels were modeled as fixed effects. Denominator degrees of freedom for tests of fixed effects were calculated using the Kenward-Roger method. LS means and standard errors were used in the calculation of least significance differences (LSD) after back-transformation for comparison among treatment means.

RESULTS AND DISCUSSION

Growing Conditions and Total Crop Production Levels

Growing season (1 May - 31 August) precipitation over the 12-yr study period averaged 181 mm, which is below the long-term (1961-1990) mean for this region of 211 mm, while growing season temperature averaged 14.6 C compared the long-term mean of 14.9 C. May to August precipitation was less than 70% of normal in 5 years (Figure 1), with 3 of these years being consecutive (2001-2003), near normal in 6 years, and above normal in one year. Overall, 5 of the growing seasons were categorized as dry and warm, 3 were dry and cool, and 4 years were moist and cool. The severe drought conditions, particularly in 1998 and 2001 to 2003, were damaging to crop establishment and development, while an early fall frost reduced grain yields and quality in 2004, and late summer hail storms resulted in moderate crop damage in 2005 and light crop damage in 2006.

Total annual grain and forage production for the complete rotation systems (Table 6)

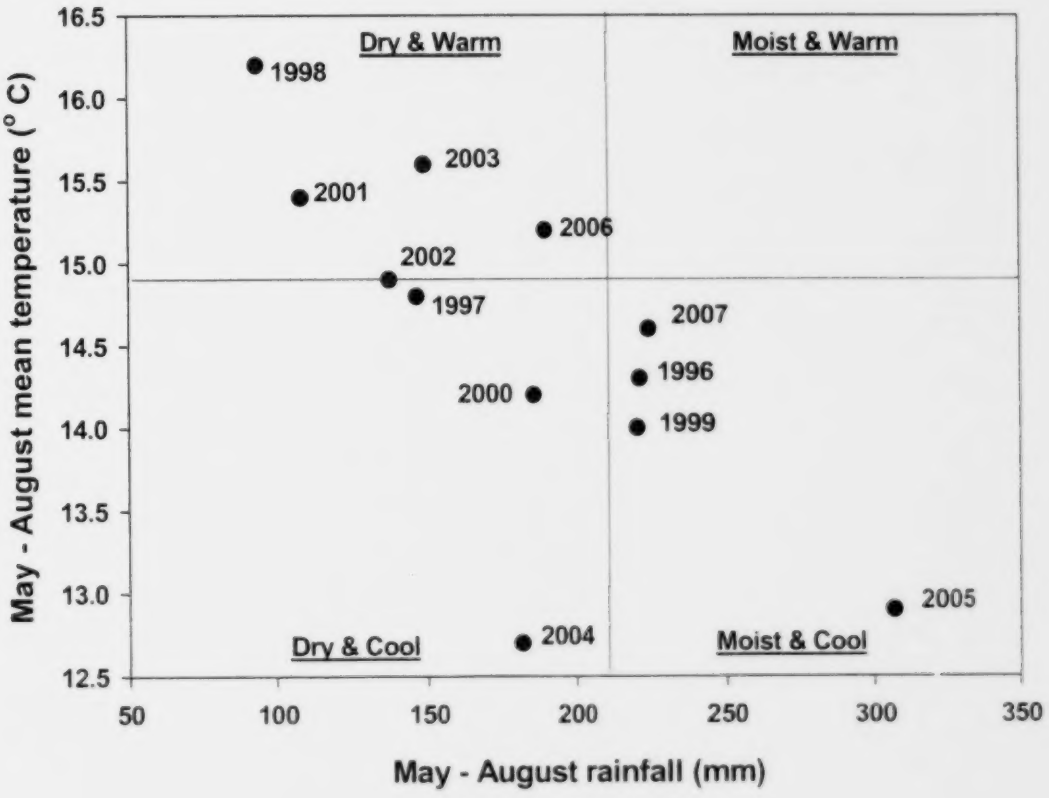

Figure 1. Growing season (1 May -31 August) precipitation and temperature conditions at Scott, Saskatchewan (1996-2007). Vertical and horizontal lines are the long-term (1961-1990) means for the region.

Table 6. Effect of input management and crop diversity on total annual production of grains and forage

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	CV[1]
	(kg ha^{-1})													%
High input														
Low crop diversity rotation	1864	1078	756	2541	1839	908	281	556	950	1496	1084	1561	1243	50
Diverse annual grains rotation	2216	1482	1305	2953	2233	783	216	779	1306	2256	1322	2406	1605	50
Grains and forage rotation	2389	1557	903	2338	2275	413	308	453	1200	2453	1721	2797	1567	56
Mean (high input)	2156	1372	988	2611	2116	701	268	596	1152	2068	1376	2255	1472	51
Reduced Input														
Low crop diversity rotation	1716	1182	1015	2036	1790	913	234	538	951	1146	1093	1533	1179	43
Diverse annual grains rotation	2113	1518	1380	2746	2478	912	231	669	1170	1948	1283	2174	1552	48
Grains and forage rotation	2352	1576	1242	1893	2111	420	342	555	992	2135	1867	2838	1527	52
Mean (reduced input)	2060	1425	1212	2225	2126	748	269	587	1038	1743	1414	2182	1419	47
Organic input														
Low crop diversity rotation	1069	785	615	1525	1060	426	25	252	871	856	851	1308	804	53
Diverse annual grains rotation	1028	655	542	1906	1097	426	28	308	993	857	659	1240	812	60
Grains and forage rotation	1511	1203	764	1598	1373	278	105	288	1333	1964	1594	2434	1204	59
Mean (organic input)	1203	881	640	1676	1177	377	53	283	1066	1226	1035	1661	940	55
Means (Low crop diversity rotation)	1550	1015	795	2034	1563	749	180	449	924	1166	1009	1467	1075	48
(Diverse annual grains rotation)	1786	1218	1076	2535	1936	707	158	585	1156	1687	1088	1940	1323	51
(Grains and forage rotation)	2084	1445	970	1943	1920	370	252	432	1175	2184	1727	2690	1433	56
Input LSD (P<0.05)	212***	142***	180***	81***	156***	189***	36***	102***	ns	153***	144***	152***		
Diversity LSD (P<0.05)	103***	63***	86***	83***	113***	78***	36***	51***	154***	94***	93***	143***		
Input x Diversity LSD (P<0.05)	257**	167***	217***	143***	223***	218***	ns	125***	290*	203***	194***	253***		

[1] Coefficient of variation.

***, **, *, and ns refer to the significance of factors at 1%, 5%, 10%, and non-significant, respectively

were closely correlated with the prevailing growing conditions (Brandt et al. 2003). In the more favorable years of 1996, 1999, 2000, and 2007, total production averaged 1954 kg ha^{-1} yr^{-1} compared to only 431 kg ha^{-1} yr^{-1} in the drought years of 2001, 2002, and 2003. Total production levels were generally similar for the respective HI and RI treatments in most years (9 of 12 years), averaging 1446 kg ha^{-1} yr^{-1} compared to 940 kg ha^{-1} yr^{-1} (or about 35% less) for the OI treatments. Of the remaining 3 years, total production was highest for the HI treatment in 2 of these years, and highest for the RI treatment in one year. Total production for the OI treatments was similar to levels produced by HI and RI in only one of the 12 years (i.e., 2004). Further, the organically managed crops tended to yield relatively less compared to the HI and RI treatments in the drier years, likely reflecting the increased soil moisture loss and greater difficulty with obtaining good stand establishment (particularly for small seeded crops) due to the greater intensity of preseeding tillage and delayed seeding used with the OI treatments. However, other factors such as lower nutrient availability, particularly available P, and greater weed competition with OI management practices may have also contributed to the lower crop yields (Entz et al. 2001; Brandt et al. 2003).

Total annual grain and forage production was also directly related to cropping intensity, with the 12-yr mean values being lowest for the DLW crop diversity treatments (1075 kg ha^{-1} yr^{-1}), intermediate for DAG (23% more), and highest for DAP (33% more) (Table 6). The tendency for higher total production with the DAP treatments in 8 of the 12 years is due largely to the inclusion of both grain and forage yields in the annual production values compared to grain only for the other crop diversity treatments. In the more moist years, total production averaged about 27% less for DLW compared to DAP and DAG, but in dry years the DLW treatments, with enhanced soil moisture levels from inclusion of summer fallow or partial-fallow in the rotations, had total production levels that were generally similar to other crop diversity treatments. Thus overall, total annual production was highest for the DAG and DAP treatments with HI and RI management, and lowest for the DLW and DAG treatments with OI management.

The year-to-year variability in total production [as measured by the coefficient of variation (CV)] tended to be lower for the RI than for the HI and OI treatments (Table 6). Further, annual production variability tended to be lower for the DLW compared to the DAG and DAP treatments. These results are attributable mainly to the benefits of reducing tillage intensity and including summer fallow or partial-fallow in the rotations as means to improve soil moisture conservation (Brandt 1992; McConkey et al. 1996), given that growing conditions were dry in 8 of 12 study years.

Our findings are in general agreement with those reported by Entz et al. (2001) who examined the cropping records of 14 organic farms in Manitoba, Saskatchewan, and North Dakota over a 6-yr period. They reported that yields of wheat grown on the organic farms averaged 77% of the long-term wheat yields grown on conventional farms, while yields of organically grown fall rye averaged 104%, flax 78%, feed barley 74%, oat 73%, field pea 67%, and canola 50% of the respective conventional crop yields. In contrast, they reported that organic forage yields were almost double those grown on conventional farms. In South Dakota, Smolik et al. (1995) compared the productivity of conventional, reduced-till, and organic farming systems over a 7-yr period in two separate experiments, one study emphasized row crops and the other small grains. They reported that in the first experiment, the organic treatment, which included alfalfa, was the most productive in terms of total dry weight of harvested plant material (57% and 72% more compared to the conventional and reduced-till systems, respectively), but in the second experiment the organic treatment, which included a legume green manure crop, had the lowest annual production (28% and 20% less compared to the respective conventional and reduced-till treatments). They also reported that the organic systems in both studies had lower year-to-year variability in production levels compared to the non-organic treatments, in contrast to our findings. In southwestern Minnesota, Mahoney et al. (2004) compared using a high level of purchased inputs, a low level of purchased inputs, and organic inputs in the management of corn (*Zea mays* L.)-soybean (Glycine max [L.] Merrill) and corn-soybean-oat/alfalfa-alfalfa

rotations. They reported that overall crop yields were not substantially different, except for the 2-yr organic rotation which had lower yields. Likewise, in Pennsylvania, Pimental et al. (2005) compared crop yields over a 22-yr period from a typical cash-grain farming system with an organic animal-based cropping syste and an organic legume-based cropping system. They reported that during the first 5 years of the experiment organic corn yields averaged 20 to 28% lower than for conventional corn, but after this transition period, yields of corn and soybean were similar for all cropping systems. Further, they reported that in dry years, corn yields were significantly higher in the two organic systems compared to the conventional system because of improved soil moisture conditions due to enhanced water holding capacity of the organically managed soil. In another Minnesota study, Archer et al. (2007) reported that yields of corn, soybean, and wheat were more than 15% lower with organic management during a 4-yr transition period versus using the highest yielding conventional practices. Several other USA studies have also reported crop yield reductions of 10 to 40% during the conversion from conventional to organic management, but in the longer term, organic crop yields often recover and compare favorably with conventionally managed crop yields, particularly if the cropping systems include legume green manure or forage crops and/or receive compost or animal manure to build soil quality and replenish nutrients (Liebhardt et al. 1989; Delate et al. 2006).

Non-Renewable Energy Input

Total energy input to the cropping systems varied with method of input management and with cropping diversity (Table 7). On average, total energy use was highest for the DAG treatments (3609 MJ ha^{-1}), and similar but lower for the DAP and DLW treatments (about 17% less than for DAG). The lower energy requirements for the DAP systems reflects, in part, that 1/2 of the land area or rotation was devoted to forage crops (mainly grass-legumes or legumes alone in later years), thereby reducing the overall need for applied N fertilizers and for machine operations (e.g., for annual seedbed preparation, planting, pesticide application). Likewise, the lower energy requirement for the DLW treatments largely reflects the high proportion of the land

Table 7. Effect of input management and crop diversity on total non-renewable energy input

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	SEM[1]
	(MJ ha^{-1})													
High input														
Low crop diversity rotation	2976	3287	3325	3113	4562	3233	3508	2641	2615	3120	4880	4052	3443	99
Diverse annual grains rotation	4540	4127	4015	3077	6661	5803	4107	3268	3335	3865	5593	4860	4438	155
Grains and forage rotation	3450	4007	2798	3008	5168	3807	3721	2798	2956	4006	4029	4509	3688	102
Mean (high input)	3655	3807	3379	3066	5465	4281	3779	2902	2969	3664	4834	4474	3856	
Reduced Input														
Low crop diversity rotation	2916	2643	3113	3734	4650	4375	3328	2984	2695	3268	4618	3872	3516	101
Diverse annual grains rotation	3504	3481	4488	3853	6189	5434	4206	3552	3635	4631	5842	5088	4492	134
Grains and forage rotation	3162	2809	3105	3535	4730	3866	3722	2945	3290	3372	3995	4127	3555	78
Mean (reduced input)	3194	2978	3569	3707	5190	4558	3752	3160	3207	3757	4818	4362	3854	
Organic input														
Low crop diversity rotation	2196	2182	2143	2145	2200	1741	1497	1515	2006	1795	2368	1767	1963	40
Diverse annual grains rotation	2072	2120	2024	2236	2098	1715	1540	1562	1970	1660	2128	1655	1898	35
Grains and forage rotation	1980	1985	1707	1869	2257	1615	1617	1458	2545	1515	1630	1498	1806	47
Mean (organic input)	2083	2096	1958	2083	2185	1690	1551	1512	2174	1657	2042	1640	1889	
Mean (all input levels)	2977	2960	2969	2952	4279	3510	3027	2525	2783	3026	3899	3492	3200	
Input LSD (P<0.05)	222***	202***	314***	290***	480***	399***	388***	233***	191***	358***	464***	360***		
Diversity LSD (P<0.05)	222***	202***	314***	ns	480***	399***	ns	233**	191***	358*	464***	360*		
Input x Diversity LSD (P<0.05)	384***	350*	ns	ns	ns	692**	ns	ns	330***	619*	ns	ns		

[1] SEM = standard error of the mean.

***, **, *, and ns refer to the significance of factors as 1%, 5%, 10%, and non-significant, respectively.

area (i.e., 1/3) that was devoted to summer fallow or to legume green manure partial fallow, again reducing the need for applied N fertilizers and field operations. These findings are in general agreement with those reported for the more drought prone Brown soil zone (Aridic Haploborolls) of Saskatchewan where total energy input averaged 2585 MJ ha^{-1} for fallow-wheat and 5274 MJ ha^{-1} for continuous wheat (Zentner et al. 1998). By comparison, in the subhumid Thin Black soil zone (Udic Borolls) of Saskatchewan, where frequency of tillage and rates of fertilization are traditionally much higher than in the semiarid Brown and Dark Brown soil zones, Zentner et al. (2004) reported that total energy input averaged 6256 MJ ha^{-1} for a spring wheat-spring wheat-winter wheat-fallow rotation, 7092 MJ ha^{-1} for a spring wheat-flax-winter wheat-pea rotation, and 8151 MJ ha^{-1} for a spring wheat-spring wheat-flax-winter wheat rotation. Similarly, in the highly productive subhumid Thick Black soil zone of Saskatchewan, Nagy et al. (2000) reported that total energy requirements were lowest for the most diversified canola-pea-flax-barley rotation (6373 MJ ha^{-1}), intermediate for canola-barley-pea-spring wheat (12% higher), and highest for the least diversified canola-spring wheat-barley-barley crop rotation (21% higher). Other studies conducted in the Canadian Prairies have also reported lower total energy requirements with rotations that include frequent fallow, or the inclusion of grain legume or perennial forage legume crops (Zentner et al. 1989; Malhi et al. 2002; Hoeppner et al. 2005); however, long-term use of frequent fallowing has also been shown to significantly reduce soil and water quality and contribute to other forms of environmental degradation (Campbell and Zentner 1993; Janzen et al. 1998; Curtin et al. 2002).

As expected, total energy input was on average highest for the HI and RI treatments (3855 MJ ha^{-1}), and lowest for OI management (51% less) (Table 7), with most of the savings coming from fertilizer and pesticide energy with organic management (Table 8). Thus, overall, the HI/DAG and RI/DAG treatments had the highest energy requirements (4465 MJ ha^{-1}), while the OI/DAP treatment had the lowest (1806 MJ ha^{-1}). The interaction of method of input management and cropping diversity was significant in 5 of 12 years (Table 7); in most of these

Table 8. Effect of input management and crop diversity on non-renewable energy requirements by resource category (1996-2007)

Input level/Crop diversity	Seed	Fertilizer[1]	Pesticides	Fuel & Oil	Machinery	Total
	(MJ ha^{-1})					
High input						
Low crop diversity rotation	338	1600	97	1146	262	3443
Diverse annual grains rotation	540	2519	140	961	278	4438
Grains and forage rotation	351	2070	83	967	217	3688
Mean (high input)	410	2063	107	1025	252	3856
Reduced Input						
Low crop diversity rotation	529	1984	320	541	142	3516
Diverse annual grains rotation	787	2632	313	569	191	4492
Grains and forage rotation	455	2066	198	674	162	3555
Mean (reduced input)	590	2227	277	595	165	3854
Organic input						
Low crop diversity rotation	564	0	0	1114	285	1963
Diverse annual grains rotation	515	0	0	1100	283	1898
Grains and forage rotation	457	75	0	1028	246	1806
Mean (organic input)	512	25	0	1081	271	1889
Mean (all input levels)	504	1438	128	900	230	3200
SEM[2]	7	59	7	13	3	

[1] Includes compost which was applied to selected crops within the Reduced input/Grains and forage rotation and the Organic input/Grains and forage rotation treatments.

[2] SEM = standard error of the mean.

years energy input for HI and RI input systems were greatest with DAG and smallest with DLW crop diversity, while for OI input systems energy input was greatest with DLW and smallest with DAP crop diversity. By comparison, the study by Hoeppner et al. (2005) in the Black soil zone of Manitoba found that a spring wheat-alfalfa-alfalfa-flax rotation used 27% less energy than a spring wheat-pea-spring wheat-flax rotation, and that use of conventional tillage management consumed 2.8 times more energy than use of organic management in the grains-only rotation and 2.2 times more energy in the grain-forage rotation. Similar energy savings have also been reported for cropping systems managed with organic practices in the USA (Karlen et al. 1995; Smolik et al. 1995; Pimentel et al. 2005).

Total energy input for all cropping systems tended to be lowest in drought years and highest in years with more favorable growing season rainfall (Table 7). This mainly reflects the higher energy requirements for harvesting, transporting, and storing the higher grain and forage yields in years with more favorable growing conditions.

With the exception of the OI treatments, energy expended on fertilizers (primarily N) represented the single largest energy input of the cropping systems, averaging 2063 MJ ha^{-1} or about 54% of the total energy input for the HI input treatments, and 2227 MJ ha^{-1} or about 58% of the total energy input for the RI input treatments (Table 8). Elsewhere in the Canadian Prairies, fertilizer energy accounted for 35% of the total energy requirements of fallow-wheat and 62% for continuous wheat rotations in the Brown soil zone (Zentner et al. 1998); it accounted for 66 to71% of the total energy requirements for diverse cropping systems in the Thin Black Chernozems (Zentner et al. 2004), and 62 to 69% of the total for diverse cropping systems in the Thick Black and Gray (Alfisol) soil zones (Nagy et al. 2000).

Fuel and lubricants represented the largest energy input for the OI treatments (1081 MJ ha^{-1} or about 57% of the total energy input), similar to that required for HI input treatments (1025 MJ ha^{-1}), but about 82% greater than that required for the RI input treatments (595 MJ ha^{-1}) which utilized conservation tillage practices. This reflects the greater reliance on mechanical tillage for

seedbed preparation, and for in-crop and post- harvest control of weeds within the OI input treatments. In contrast, Hoeppner et al. (2005) reported that in the Black Chernozemic soil zone of Manitoba, use of organic management provided fuel energy savings of about 11% compared to conventional management in both spring wheat-pea-spring wheat-flax and spring wheat-alfalfa-alfalfa-flax rotations. In the Brown soil zone where tillage intensity is lowest, use of minimum and zero tillage (compared to conventional tillage) practices provided savings in fuel energy in a 2-yr fallow-wheat rotation of about 14% and 32%, respectively, but only about a 6% fuel energy savings in continuously cropped wheat (Zentner et al. 1998). In the more moist Black and Gray soil zones of Saskatchewan, use of conservation tillage practices provided fuel energy savings of about 11 to 15% with minimum tillage and 37 to 40% with zero tillage practices (Nagy et al. 2000; Zentner et al. 2004).

Pesticides represented from 2 to 3% of the total energy input for the HI input treatments and from 6 to 9% of the total for the RI input treatments. Energy embodied in machinery and storage buildings differed marginally among cropping systems, with the requirements lowest for RI and highest for the OI input treatments. Seed energy requirements averaged 10 to 12% of total for HI, 13 to 18% for RI, and 25 to 29% for OI treatments, reflecting the higher seed rates used with the latter cropping systems. These results are generally consistent with those reported in other Canadian Prairie studies (Zentner et al. 1998, 2004; Nagy et al. 2000; Hoeppner et al. 2005).

Energy Output

Over the 12-year study period, average energy output was highest for the DAP systems (25008 MJ ha^{-1}), intermediate for DAG (5% less), and lowest for the DLW systems (20% less) (Table 9). Further, energy output was typically highest for the HI input systems (26543 MJ ha^{-1}), only about 4% lower with RI inputs, and 37% lower with OI input management. The much lower energy output from the OI systems directly reflects the consistently lower crop yields that were produced with OI management (Brandt et al. 2003). The relatively high energy output from DAP

Table 9. Effect of input management and crop diversity on total energy output

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	SEM[1]
	(MJ ha^{-1})													
High input														
Low crop diversity rotation	35598	20142	13771	46959	34354	17211	5798	9942	18692	28127	20535	29413	23386	1684
Diverse annual grains rotation	43390	27103	23406	54613	42173	14610	4335	13993	23803	27337	25403	44968	28761	2114
Grains and forage rotation	42054	26117	14999	42079	38909	7019	5738	7801	20461	41576	30769	52267	27482	2278
Mean (high input)	40347	24454	17392	47884	38479	12947	5290	10579	20985	32347	25569	42216	26541	
Reduced Input														
Low crop diversity rotation	31215	22104	19061	38240	33499	17270	5264	9706	18670	22668	20592	28932	22268	1356
Diverse annual grains rotation	39587	27937	25157	50553	46078	16831	4595	12151	21532	22483	25216	40690	27734	1977
Grains and forage rotation	39345	26683	21456	34539	35243	7418	6581	9583	17008	37135	33142	53140	26773	2060
Mean (reduced input)	36716	25575	21891	41111	38273	13840	5480	10480	19070	27429	26317	40921	25592	
Organic input														
Low crop diversity rotation	19550	14596	10988	28263	19366	8063	429	4291	15563	14500	15617	23933	14597	1131
Diverse annual grains rotation	18084	12188	9392	34446	18438	8036	475	5193	17446	14457	12405	22660	14435	1259
Grains and forage rotation	25333	20373	13174	29358	23049	4814	1762	4871	22033	31549	27639	45260	20768	1834
Mean (organic input)	20989	15719	11185	30689	20284	6971	889	4785	18347	20169	18554	30618	16600	
Mean (all input levels)	32684	21916	16823	39894	32345	11252	3886	8615	19468	26658	23480	37918	22912	
Input LSD (P<0.05)	4617***	2541***	2242***	5569***	4078***	2042***	1039***	1570***	ns	4764***	3821***	5752***		
Diversity LSD (P<0.05)	4617*	2451**	ns	5569**	ns	2042***	1039***	1570*	ns	4764***	3821***	5752***		
Input x Diversity LSD (P<0.05)	ns	4246*	4230*	ns	ns	ns	1800**	ns	ns	ns	ns	ns		

[1] SEM = standard error of the mean.

***, **, *, and ns refer to the significance of factors as 1%, 5%, 10%, and non-significant, respectively.

systems reflects the fact that the entire harvested biomass of forage crops was included as energy output, while for grain crops only the seed was included because crop residues were returned to the land to help protect the soil from erosion and to maintain soil quality (Brandt et al. 2003). The interaction of method of input management and crop diversity was significant in only 1997, 1998 and 2002; in most of these years energy output was greatest for HI and RI input systems with DAG crop diversity while for OI input it was greatest with DAP crop diversity.

Energy output for the cropping systems also varied greatly among years (Table 9), generally reflecting the amount and distribution of growing season precipitation and temperatures at the test site (Figure 1). For example, in 2002, a year with less than 2/3 of normal precipitation, energy output was low for all treatments, but was near zero for the OI systems. This latter result reflects the complete failure of most crops due to the severe drought conditions. Energy output was highest for the DLW and DAG cropping systems in 1999, a year with near normal growing season precipitation, but also generally cool growing conditions. The DAP treatments produced their highest energy output in 2007, a year with above-average early season rainfall. In 2005, the year with greatest growing season rainfall but also high temperature stress during the grain filling period, energy output for the cropping system ranked only about fifth highest. Overall, energy output was typically greatest and generally similar for the HI/DAG, RI/DAG, HI/DAP, and RI/DAP treatments (27688 MJ ha^{-1}) and lowest for OI/DLW and OI/DAG (14513 MJ ha^{-1} or 48% less). The HI/DLW and RI/DLW treatments, which were characterized by low cropping intensity and high frequency of summer fallow or legume green manure partial fallow, ranked second highest in terms of energy output (about 18% less than the best treatments).

In comparison with other studies, Hoeppner et al. (2005) reported that in the Black soil zone of Manitoba where moisture is less restrictive and crop yields are traditionally higher than in Dark Brown and Brown soil zones, annual energy output averaged 29912 MJ ha^{-1} with a 4-yr grains-only rotation and 69982 MJ ha^{-1} from a 4-yr mixed grain-forage rotation that included 2 years of alfalfa hay. Furthermore, they reported that energy output for these rotations averaged

29% lower with organic compared to conventional practices, which was also attributed to lower crop yields with organic management. In a Thin Black soil at Indian Head, Saskatchewan, Zentner et al. (2004) reported that annual energy output from a 4-yr monoculture cereal rotation that included fallow once every 4 years averaged 32315 MJ ha^{-1}, while energy output averaged 41287 MJ ha^{-1} (or 28% more) from a 4-yr cereal-oilseed rotation and 42961 MJ ha^{-1} (33% more) from a 4-yr cereal-oilseed-pulse rotation. Further, they reported that tillage method had little influence on energy output for the monoculture cereal and cereal-oilseed-pulse rotation, but for the cereal-oilseed rotation energy output was higher with minimum and zero tillage compared to conventional tillage management. Generally similar findings have also been reported for the Brown soil zone (Zentner et al. 1998) and for the Thick Black and Gray Luvisolic soil zones of Saskatchewan (Nagy et al. 2000).

Energy Use Efficiency

Net energy production (energy output minus energy input) displayed generally similar trends among cropping systems as for gross energy output (Table 10). Net energy production was highest for DAP systems (21981 MJ ha^{-1}), intermediate for DAG (9% less), and lowest for the DLW systems (22% less). Similarly, net energy production was highest for the HI and RI input systems (22212 MJ ha^{-1}) and lowest for the OI systems (34% less). These results suggest (to date) that in order to produce the same level of net energy output for consumption by humans or animals, substantially more land area will need to be devoted to production with OI than with the other methods of input management. Thus, with a limited land base, this may become an important issue for producers and society in terms of meeting the food requirements for a growing world population (Edwards-Jones and Howells 2001; Hoeppner et al. 2005). These results also suggests there is need for additional investment in research to enhance crop yields and to resolve other management issues related to organic production (Entz et al. 2001; Hoeppner et al. 2005).

In contrast to net energy, grain plus forage production per unit of energy input (Table 11)

Table 10. Effect of input management and crop diversity on net energy production

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	SEM[1]
	(MJ ha^{-1})													
High input														
Low crop diversity rotation	32622	16855	10446	43846	29792	13978	2290	7301	16077	25097	15655	25361	19943	1672
Diverse annual grains rotation	38850	22976	19391	51536	35512	8807	228	10725	20468	23472	19810	40108	24324	2107
Grains and forage rotation	38604	22110	12201	39071	33741	3212	2017	5003	17505	37570	26740	47758	23794	2233
Mean (high input)	36692	20647	14013	44818	33015	8666	1512	7676	18017	28713	20735	37742	22687	
Reduced Input														
Low crop diversity rotation	28299	19461	15948	34506	28849	12895	1936	6722	15975	19400	15974	25060	18752	1331
Diverse annual grains rotation	36083	24456	20669	46700	39889	11397	389	8599	17897	17852	19374	35602	23242	1959
Grains and forage rotation	36183	23874	18351	31004	30513	3552	2859	6638	13718	33763	29147	49013	23218	2038
Mean (reduced input)	33522	22597	18323	37403	33084	9281	1728	7320	15863	23672	21498	36558	21737	
Organic input														
Low crop diversity rotation	17354	12414	8845	26118	17166	6322	-1068	2776	13557	12705	13249	22166	12634	1107
Diverse annual grains rotation	16012	10068	7368	32210	16340	6321	-1065	3631	15476	12797	10277	21005	12537	1239
Grains and forage rotation	23353	18388	11467	27489	20792	3199	145	3413	19488	30034	26009	43762	18962	1830
Mean (organic input)	18906	13623	9227	28606	18099	5281	-663	3273	16174	18512	16512	28978	14711	
Mean (all input levels)	29707	18956	13854	36942	28066	7743	859	6090	16685	23632	19582	34426	19712	
Input LSD (P<0.05)	4503***	2339***	2280***	5357***	3853***	1854***	1115***	1499***	2974*	4719***	ns	5661*		
Diversity LSD (P<0.05)	4503*	2339**	2280***	5357**	3853***	1854***	1115***	ns	ns	4719***	3806***	5661***		
Input x Diversity LSD (P<0.05)	ns	ns	ns	ns	6674**	3211**	1931**	ns	ns	ns	ns	ns		

[1] SEM = standard error of the mean.

***, **, *, and ns refer to the significance of factors as 1%, 5%, 10%, and non-significant, respectively.

Table 11 Effect of input management and crop diversity on yield of grain plus forage per unit of energy input

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	SEM[1]
	(kg GJ^{-1})													
High input														
Low crop diversity rotation	626	328	227	816	403	281	80	211	363	479	222	385	369	28
Diverse annual grains rotation	488	359	325	960	335	135	53	238	392	584	236	495	383	34
Grains and forage rotation	692	389	323	777	440	108	83	162	406	612	427	620	420	32
Mean (high input)	602	359	292	851	393	175	72	204	387	558	295	500	391	
Reduced Input														
Low crop diversity rotation	588	447	326	545	385	209	70	180	353	351	237	396	341	30
Diverse annual grains rotation	603	436	307	713	400	168	55	188	322	421	220	427	355	26
Grains and forage rotation	744	561	400	536	446	109	92	188	302	633	467	688	430	3[1]
Mean (reduced input)	645	481	344	598	410	162	72	185	326	468	308	504	375	
Organic input														
Low crop diversity rotation	487	360	287	711	482	245	17	166	434	477	359	740	397	21
Diverse annual grains rotation	496	309	268	852	523	248	18	197	504	516	310	749	416	34
Grains and forage rotation	763	606	448	855	608	172	65	198	524	1296	978	1625	678	66
Mean (organic input)	582	425	334	806	538	222	33	187	487	763	549	1038	497	
Mean (all input levels)	610	422	323	752	447	186	59	192	400	597	384	681	421	
Input LSD (P<0.05)	ns	62**	ns	101**	ns	ns	55***	ns	ns	ns	257*	191*		
Diversity LSD (P<0.05)	101***	62***	49***	101***	70***	36***	55***	47**	72**	152***	257***	191***		
Input x Diversity LSD (P<0.05)	ns	107***	ns	ns	ns	ns	ns	ns	ns	ns	ns	331**		

[1] SEM = standard error of the mean.

***, **, *, and ns refer to the significance of factors as 1%, 5%, 10%, and non-significant, respectively.

and energy output/energy input ratio (Table 12) were highest for the OI managed systems (501 kg GJ^{-1} of energy input and 8.85 ratio, respectively), and lower but generally similar for the HI and RI input systems (377 kg GJ^{-1} and 6.79 ratio, respectively). The high energy ratio for the OI systems reflects that although energy output is substantially lower with OI than for other input management methods, total energy input is even much lower, resulting in the relatively high indicators of energy use efficiency. Further, both measures of energy use efficiency tended to be highest for the DAP systems, and lowest for the DLW and DAG cropping systems, reflecting that the entire above-ground biomass of forages crops was taken as energy output compared to the seed only for grain crops. Thus overall, OI/DAP ranked highest as the most energy efficient cropping system, while RI/DLW and RI/DAG generally ranked lowest in energy use efficiency. These findings are in general agreement with those reported by Hoeppner et al. (2005) and others (Smolik et al. 1995; Nagy et al. 2000; Zentner et al. 2004). Earlier studies of the energy use efficiency of Saskatchewan annual grain production systems during the 1950s and 1960s reported energy use efficiencies of about 220 kg of grain produced GJ^{-1} of energy input and an energy output/energy input ratio of about 3.5 (Hopper 1984). However, more recent studies have reported that the energy use efficiency of Canadian agriculture production systems have generally increased over time as a result of technology driven increases in output outpacing increases (and in some cases decreases) in energy inputs (Swanton et al. 1996; Weseen et al. 1999).

CONCLUSIONS

This study examined non-renewable energy inputs and energy use efficiency of nine cropping systems, comprised of three levels of input use [high (HI), reduced (RI), and organic (OI)] and three levels of cropping diversity [low cropping diversity and intensity (DLW), diversified cropping using annual grains (DAG), and diversified cropping using annual grains and perennial forages (DAP)], over a 12 year period in the Dark Brown soil zone of the Canadian Prairies. Energy inputs were highest for the DAG treatments, and similar but lower for the DAP and DLW diversity treatments. The lower energy use with the DAP systems was directly related

Table 12. Effect of input management and crop diversity on energy output/energy input ratio

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	SEM[1]
High input														
Low crop diversity rotation	11.96	6.13	4.14	15.08	7.53	5.32	1.65	3.76	7.15	9.04	4.21	7.26	6.94	0.53
Diverse annual grains rotation	9.56	6.57	5.83	17.75	6.33	2.52	1.06	4.28	7.14	7.07	4.54	9.25	6.82	0.60
Grains and forage rotation	12.19	6.52	5.36	13.99	7.53	1.84	1.54	2.79	6.92	10.38	7.64	11.59	7.36	0.58
Mean (high input)	11.24	6.41	5.11	15.61	7.13	3.23	1.42	3.61	7.07	8.83	5.46	9.37	7.04	
Reduced Input														
Low crop diversity rotation	10.70	8.36	6.12	10.24	7.20	3.95	1.58	3.25	6.93	6.94	4.46	7.47	6.43	0.39
Diverse annual grains rotation	11.30	8.03	5.61	13.12	7.45	3.10	1.09	3.42	5.92	4.85	4.32	8.00	6.35	0.49
Grains and forage rotation	12.44	9.50	6.91	9.77	7.45	1.92	1.77	3.25	5.17	11.01	8.30	12.88	7.53	0.54
Mean (reduced input)	11.48	8.63	6.21	11.04	7.37	2.99	1.48	3.31	6.01	7.60	5.69	9.45	6.77	
Organic input														
Low crop diversity rotation	8.90	6.69	5.13	13.18	8.80	4.63	0.29	2.83	7.76	8.08	6.60	13.54	7.20	0.55
Diverse annual grains rotation	8.73	5.75	4.64	15.41	8.79	4.69	0.31	3.32	8.86	8.71	5.83	13.69	7.39	0.60
Grains and forage rotation	12.79	10.26	7.72	15.71	10.21	2.98	1.09	3.34	8.66	20.82	16.96	30.21	11.73	1.18
Mean (organic input)	10.14	7.57	5.83	14.77	9.27	4.10	0.56	3.16	8.43	12.54	9.80	19.15	8.78	
Mean (all input levels)	10.95	7.53	5.72	13.80	7.92	3.44	1.15	3.36	7.17	9.66	6.98	12.66	7.53	
Input LSD (P<0.05)	ns	1.07***	ns	1.72***	ns	0.65**	0.95***	0.79**	ns	ns	4.30*	3.53***		
Diversity LSD (P<0.05)	1.69**	1.07***	0.79***	1.72***	1.18**	0.65***	0.95***	0.79*	ns	2.72***	4.30***	3.53***		
Input x Diversity LSD (P<0.05)	ns	1.86**	ns	ns	ns	ns	ns	ns	ns	ns	ns	6.12**		

[1] SEM = standard error of the mean.

***, **, *, and ns refer to the significance of factors as 1%, 5%, 10%, and non-significant, respectively.

to the inclusion of legume forages in the rotation which reduced the need for applied N fertilizer and machine operations. The lower energy requirements of the DLW input systems were the result of including summer fallow or legume green manure partial fallow in the rotation once every three years, which reduced the need for fertilizers and machine operations; however, the practice of frequent summerfallowing has been clearly linked to enhanced degradation of the soil, water, and air resources in this region. As expected, energy requirements were highest for the HI and RI input systems and lowest for OI management. The use of non-chemical means of pest control, legume green manures, and other organic management practices provided an energy savings of about 51% compared to the HI and RI input treatments. In contrast, however, energy output and net energy production from the cropping systems averaged about 35% lower with organic management because of lower crop yields to date. Energy output was highest with the DAP systems (because the entire biomass is harvested, not just the grain), intermediate for DAG, and lowest for the DLW diversity treatments due mainly to the lower cropping intensity of these latter systems.

Despite the lower energy output from the OI systems, energy use efficiency, measured as yield produced per unit of energy input, or as energy output/energy input ratio, was highest with OI management, with the OI/DAP cropping system being most efficient. The cropping systems with the lowest energy use efficiency were RI/DLW and RI/DAG.

Our findings provide support for the movement of Canadian Prairie producers to organic management as a means of reducing the reliance on non-renewable energy inputs and improving overall energy use efficiency of their cropping systems. However, in doing so, the quantity of food and fibre produced for use by humans and animals with organic management will be substantially less, unless crop yields can be improved through further research and refinement of organic production practices. Our findings also suggest that moving away from the traditional monoculture cereal rotations with frequent summerfallowing to extended and diversified rotations that use minimum tillage methods, although resulting in a significant increase in energy output,

will not significantly reduce the overall reliance on non-renewable energy inputs nor enhance energy use efficiency unless perennial legume forages and/or annual grain legumes are included in the cropping systems.

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PART II

ECONOMIC RETURNS AND RISKINESS

BACKGROUND AND OBJECTIVES

Land use practices throughout the Northern Great Plains are undergoing significant change in response to rising input costs, expanding global markets, and growing concerns over food safety and environmental degradation (Padbury et al. 2002; Pimentel et al. 2005). Producers have begun to extend and diversity their traditional cereal-based cropping systems by reducing summer fallow and including oilseed and legume crops in the rotation, together with use of conservation tillage methods, to capitalize on the rotational benefits of mixed cropping systems, reduce the need for synthetic N fertilizer and fossil energy, and protect the quality of the soil, water and air resources (Smolik et al. 1995; Campbell et al. 2002). Other producers have become increasingly interested in employing low-input and organic production methods as means to further reduce the reliance on purchased inputs and to add value to the products produced (Entz et al. 2001; Smith et al. 2004; Pimental et al. 2005).

The use of minimum and zero tillage practices for annual crops offer producers the opportunity to enhance soil moisture conservation, reduce soil erosion, sequester soil carbon, and reduce greenhouse gas emissions compared to conventional tillage practices (Acton and Gregorich 1995; Janzen et al. 1999). At the same time, however, these practices pose additional challenges in managing problem weeds and nutrient availability compared to conventional tillage practices (Lafond et al. 1996; Campbell et al. 1988; Derksen et al. 2002). In the semiarid Brown (Aridic Haploborolls) and Dark Brown (Typic Boroll) soil zones, researchers have seldom reported higher crop yields when conservation tillage practices are used in monoculture cereal and fallow-based rotations (Brandt 1992; McConkey et al. 1996). Results of economic studies have also reported little or no economic advantage over conventional tillage practices for these cropping systems (Smith et al. 1996; Zentner et al. 1996b). Although reducing tillage intensity lowers costs for labor, fuel, and machine repair and overhead, these savings were generally more than offset by higher expenditures for herbicides and N fertilizer. However, when conservation

tillage practices are combined with mixed cereal-oilseed-pulse rotations, consistent yield increases are more common (Miller et al. 2001; Lafond et al. 1996). The synergism that occurs between conservation tillage and mixed cropping systems have been attributed to many factors including enhanced soil moisture availability from improved snow trap, reduced evaporation losses, and lower moisture use by some crops (e.g., pulses); improved crop establishment due to better surface soil moisture and micro-climatic conditions, particularly for small seeded crops; increased nutrient use efficiency resulting from better synchrony between nutrient release via mineralization of previous crop residues and nutrient uptake by the current crop; and enhanced control of weeds and other crop pests due to additional chemical and non-chemical corrective options (Campbell et al. 1990; Lafond et al. 1996; Derksen et al. 2002). Although few economic studies of these latter cropping systems have yet been completed for Canadian Prairie conditions, most have reported significant economic gains over conventional cropping systems due to the enhanced crop yields and improved grain quality (e.g., grain protein), production of higher valued crops (oilseed and pulse versus cereals), and in some cases, lower overall production costs (Zentner et al. 1992a, 2002a, 2002b).

Organic agriculture relies on the use of mixed crop rotations, legume green manure and cover crops, the addition of animal manures and/or compost, and on mechanical tillage to maintain the health of the soil and environmental resources, recover nutrients from lower soil depths, and minimize the influences of crop pests (Schneeberger et al. 2002; Pimentel et al. 2005). Organic systems typically produce lower crop yields than conventional cropping systems under Canadian Prairie conditions (Entz et al. 2001; Brandt et al. 2003). Further they require producers to incur substantial transition costs such as investment in soil-building crops and/or the addition of organic amendments to enhance soil organic matter levels and replenish soil nutrients, plus often having to make changes to machine inventory items. In addition, they require substantial time and effort to learn and master organic production practices and to discover and secure marketing opportunities. Organic producers must also go through a 3-yr certification

period during which they are required to use certified organic seed and management methods, but must sell their grain and forage products at commercial or non-organic prices. Once the certification period is completed, however, most organic products can typically be sold at price premiums over conventionally produced products, and these higher revenues combined with savings in expenditures for inorganic fertilizers and chemicals may result in improvements to overall net farm income. Studies that have examined the economic merits of organic agriculture (compared to conventional agriculture) have reported that the main determinants of profitability were relative crop yields, extent of the cost savings for purchased inputs, available supply of unpaid family labor, existence of adequate price premiums for products, and the magnitude and duration of reduced income during the certification/transition period (Schneeberger et al. 2002; Smith et al. 2004; Pimentel et al. 2005).

The degree to which producers ultimately adopt these new or alternative crop production systems depends largely on their inherent ability to lower production costs, generate increased net returns, or reduce the overall financial risk compared to current cropping practices (Zentner et al. 2002b). The objective of this study was to determine and compare production costs, net returns, and riskiness of nine cropping systems, representing three levels or methods of input management (high, reduced, and organic) and three levels of cropping diversity (low cropping diversity and intensity, diversified cropping using annual grains, and diversified cropping using annual grains and perennial forages), over a 12-yr period (1996-2007) for the semiarid Dark Brown soil zone of the Canadian Prairies.

MATERIALS AND METHODS

Experimental data

The design and methods for the field experiment have been described in Part I of this report.

Economic analysis

The economic analysis follows methods used previously by Zentner et al. (1992a) and Zentner and Campbell (1988). Spreadsheet programs were developed to determine and compare

annual total and unit costs of production, amount and seasonal distribution of resource needs (e.g., seed, fertilizer, pesticides, fuel, machine repair, labor, specialized equipment needs), level of gross and net returns (i.e., income remaining after paying for all cash costs, plus labor and overhead costs for machines and buildings), and riskiness (income variability) for each cropping system. In addition, the net present values (NPV), which incorporate both the timing and magnitude of net returns, were computed for each cropping system using a discount rate of 5% (Doll and Orazem 1978). No allowance was made for investment costs associated with land equity, or for differences in management requirements among the treatments.

The experimental data were extrapolated to the farm-level using a representative farm size of 907 ha and with a typical complement of machinery for each cropping system. Costs for inputs were held constant at their 2007 levels (Table 1 and Table 2) (Saskatchewan Agriculture and Food, 2007; University of Saskatchewan, 2007). Conventionally produced products were valued at their respective 2007-08 average farm-gate prices (net of elevation, transportation, and storage costs) (Table 3). Organically produced products were valued using the relative prices of organic versus conventional grains as established by the Saskatchewan Crop Insurance Corporation, namely an organic/conventional price ratio of 1.8 for field pea and cereal crops, 1.3 for canola, and 1.5 for mustard, plus an assumed organic/conventional price ratio for hay of 1.15. Wheat prices were adjusted for protein concentrations obtained in the respective treatments using the 2007-08 protein price premium schedules as established by the Canadian Wheat Board. Organic price premiums were not permitted for organic products produced in 1996 and 1997 as the farm was still completing the 3-yr organic certification period. The analysis was repeated for five price scenarios reflecting current and possible future declines in organic price premiums: full price premiums received on 100% of the organically grown grains (reflects an established organic farm capable of selling all of its produce at current organic prices); 75%, 50% and 25% of current organic price premiums; and no organic price premiums. In addition, the sensitivity of the results to changes in product price levels and major input costs were examined. The relative profitability

Table 1. Purchased input costs

Herbicides	**Cost ($)**	**Unit**
2,4-D amine 500	6.47	L
2,4-D ester 500	7.80	L
Achieve DG	157.50	kg
Assure II	81.46	L
Attain	22.56	ha
Avadex BW	2.61	kg
Banvel II	38.18	L
Buctril M	17.38	L
Cobutox 600	21.00	L
Dyvel DS	13.91	L
Edge	2.17	kg
Glyphosate	7.40	L
Horizon	185.37	L
Liberty	14.04	L
Lontrel	146.53	L
Mataven	11.80	L
MCPA Amine	7.83	L
MCPA Sodium Salt	6.12	L
Muster	3.17	g
Odyssey	1.38	g
Pardner	21.55	L
Pea Pack	19.12	ha
Poast	84.85	L
Refine Extra	0.74	g
Reglone	23.45	L
Rustler	5.99	L
Select	221	L
Sencor	70.25	kg
Tropotox Plus	13.25	L
Insecticides		
Decis	86.50	L
Lorsban 4E	17.70	L
Matador	139.82	L
Sevin	14.00	L
Fungicides		
Tilt	69.85	L
Seed Treatments		
Jump Start	0.0154	kg seed
Premiere Plus	0.0077	kg seed
Provide	0.0077	kg seed
Vitavax Dual	0.1358	kg seed
Vitavax Powder	0.0792	kg seed
Vitavax RS	0.1470	kg seed
Seed Inoculants	**Cost ($)**	**Unit**
Alfalfa	0.22	kg seed

Field Pea	0.0456	kg seed
Lentil	0.0759	kg seed
Sweet Clover	0.22	kg seed
Seed costs		
Alfalfa – conventional	8.27	kg
Alfalfa – organic	10.34	kg
Barley – conventional	0.22	kg
Barley – organic	0.38	kg
Bromegrass – conventional	5.50	kg
Bromegrass – organic	6.88	kg
Canola – conventional	9.37	kg
Canola –organic	16.55	kg
Indianhead Black Lentil – conventional	0.46	kg
Indianhead Black Lentil – organic	1.04	kg
Flax – conventional	0.38	kg
Mustard – organic	8.63	kg
Oat – conventional	0.28	kg
Oat – organic	0.64	kg
Pea – conventional	0.24	kg
Pea – organic	0.45	kg
Rye – conventional	0.18	kg
Sweet Clover – organic	1.57	kg
Wheat – conventional	0.25	kg
Wheat – organic	0.44	kg
Fertilizers		
12-51-0	684	t
46-0-0	629	t
34-0-0	480	t
Compost	11.13	t
Fuel (net farm price)		
Diesel	1.05	L
Gasoline	0.99	L

Table 2. Machine operations, storage, and other related costs

Field operation	Cost ($ ha^{-1})
Bale (large round)	24.87[1]
Broadcast	6.33
Combine – cereals	40.43[1]
Combine – oilseeds	46.10[1]
Combine – pulses	47.73[1]
Disk drill	29.08
Harrow	6.14
Harrow pack	9.50
Harrow pack & harrow	14.72[3]
Haul water	1.17[2]
Heavy duty cultivator	13.06
Heavy duty cultivator & harrow packer	19.16[3]
Heavy duty cultivator with tine harrows	14.76
Heavy duty cultivator with tine harrow & harrow packer	20.79[3]
Heavy duty cultivator with trailing rodweeder	14.76
Heavy harrow	5.91
Hoe drill	26.85
Land roller	10.25
Manure application (compost)	25.21
Medium duty cultivator	12.13
Medium duty cultivator with tine harrows	13.76
Medium duty cultivator with tine harrows and trailing rodweeder	15.38
Mower-conditioner	31.21
Rodweed	9.48
Pickup truck (farm business)	6.03
Spray	7.65
Swath	21.45
Transport farm inputs (farmyard to field)	4.51
Transport grain (field to farmyard)	12.32[1]
Transport grain (farmyard to elevator)	13.99[1]
Transport bales (field to farmyard)	12.07
Buildings	
Grain storage	3.60[1]
Shop and machine storage	5.76
Other related costs	
Interest rate	5.70 (%)
Labor	11.00 ($ hr^{-1})
Organic certification and inspection fees	4.94
Land taxes	13.70
Miscellaneous	12.87

[1] Costs are yield dependent; value shown for a yield of 2000 kg ha^{-1}.
[2] Shown per spray application.
[3] Reflects a combined field operation.

Table 3. Net farm prices ($ t^{-1}) for conventional and organically grown crops

Crop (% Protein)	Conventional	Organic
Wheat (≤11.99%)	305.14	549.25
Wheat (12.0 to 12.499%)	306.09	550.96
Wheat (12.5 to 12.999%)	307.29	553.12
Wheat (13.0 to 13.499%)	308.59	555.46
Wheat (13.5 to 13.999%)	310.59	559.06
Wheat (14.0 to 14.499%)	313.09	563.56
Wheat (14.5 to 14.999%)	315.49	567.88
Wheat (15.0 to 15.499%)	318.00	572.40
Wheat (≥15.5%)	319.34	574.81
Barley – feed	214.99	386.98
Barley – malt	224.18	403.52
Rye	210.55	-
Canola	555.47	722.11
Mustard	-	983.46
Oat	164.80	296.64
Flax	749.52	-
Pea	325.09	585.16
Hay (dry weight basis)	81.00	93.15

of the treatments was examined for a 25% increase and a 25% decrease in product price assumptions, holding input costs constant at the base levels. In addition, the relative economic performance of treatments were examined for a 50% increase (and decease) in the cost of fuel and fertilizer, holding product prices and other input costs constant at the base levels. The evaluations were conducted with and without participation in the Canada/Saskatchewan all-risk crop insurance program to assess its effectiveness in reducing the overall financial risk associated with the cropping systems. For the former analysis, all grain crops were insured at the 70% yield coverage level for the respective conventional and organic treatments (Saskatchewan Crop Insurance Corporation, 2007); forage and legume green manure crops were assumed to be uninsured. The 2007 premium rates and payout criteria for Risk Area #20 of Saskatchewan were assumed for the respective conventional and organically grown grains (Table 4).

All findings were expressed on per hectare basis for the complete cropping systems, which includes the costs and returns for all cropped and fallow phases of each treatment. Data for the establishment year of the experiment (1995) were excluded because not all crops were yet in proper sequence, and thus their performance would not be reflective of true treatment effects. All data were initially subjected to analysis of variance on an annual basis for split-split plot designs using Proc Mixed, with the residuals tested for normality with Proc Univariate of SAS (SAS Inst. Inc., 2006a). The presence of an excess of zeros in the data created an over-dispersion problem, hence the data were transformed using a gamma distribution (Littell et al. 2006) and subsequently analyzed using PROC GLIMMIX of SAS Version 9.1 (SAS Inst. inc., 2006b). Input and diversity levels were modeled as fixed effects. Denominator degrees of freedom for tests of fixed effects were calculated using the Kenward-Roger method. LS means and standard errors were used in the calculation of least significance differences (LSD) after back-transformation for comparison among treatment means. ($P<0.05$) Riskiness was assessed using stochastic dominance analysis (Goh et al. 1989) to compare the probability distributions of net returns for each cropping system for groups of producers having low, medium, and high risk aversion as defined by Zentner et al.

Table 4. All-risk crop insurance premiums and yield guarantees (70% coverage), Risk Area #20 of Saskatchewan, 2007[1]

Crop	Conventional management				Organic management			
	Fallow		Stubble		Fallow		Stubble	
	Premium ($ ha^{-1})	Yield guarantee (kg ha^{-1})	Premium ($ ha^{-1})	Yield guarantee (kg ha^{-1})	Premium ($ ha^{-1})	Yield guarantee (kg ha^{-1})	Premium ($ ha^{-1})	Yield guarantee (kg ha^{-1})
Wheat	12.68	1685	11.76	1565	22.78	1347	17.22	1017
Barley	-	-	13.57	1861	-	-	19.82	1209
Rye	-	-	11.39	1622	-	-	-	-
Flax	-	-	17.49	816	-	-	-	-
Canola	23.13	1085	19.91	934	18.83	543	16.19	467
Mustard	-	-	-	-	40.52	721	20.51	364
Pea	-	-	15.32	1522	-	-	20.71	913

[1] Crop insurance prices used in determining payouts for conventional crops: wheat $135 t^{-1}, barley $100 t^{-1}, rye $90 t^{-1}, flax $232 t^{-1}, canola $340 t^{-1}, and field pea $140 t^{-1}; for organic crops: wheat $243 t^{-1}, barley $180 t^{-1}, canola $442 t^{-1}, mustard $525 t^{-1} and field pea $252 t^{-1}.

(1992b).

RESULTS AND DISCUSSION

Production Costs

Total costs (excluding crop insurance premiums) were significantly influenced by input level in 8 of 12 years and by crop diversity in all years, with the interaction of input level and crop diversity also significant in 8 years (Table 5). Total costs for the OI treatments averaged \$262 ha^{-1}, which was \$49 ha^{-1} lower (or 16% less) than for the HI and RI treatments. We found relatively little difference in total costs for the respective HI and RI treatments in most years, despite the intention within the research protocol to reduce the overall reliance on purchased inputs with the RI treatments through use of an integrated approach to nutrient and pest management. Further, total costs were lowest for the DLW treatments (\$264 ha^{-1}), and higher but similar for the more intensively cropped DAG and DAP systems (\$46 ha^{-1} more). Thus as expected, total production costs were generally lowest for the OI/DLW and highest for the HI/DAG treatments. Production costs varied relatively little across years for most treatments (as indicated by CV), but tended to be higher in years with more favorable growing conditions due mainly to the increased costs associated with harvesting, transporting and storing the higher crop yields and the need for additional weed control measures for some treatments in these years. By comparison, in the Dark Brown soil zone of southern Alberta, Smith et al. (2004) reported an annual cost saving of 13% with an organically managed wheat-legume green manure rotation compared to a no-till managed wheat-fallow rotation, and a 32% cost saving with an organically managed cereal-pulse-oilseed-legume green manure rotation compared to a no-till cereal-pulse-oilseed-fallow rotation, but a 31% increase in annual costs for an organically managed 4-yr mixed grain-forage rotation due largely to the high costs associated with purchasing and applying composted manure to this cropping system. In Ontario, Stonehouse (1996) reported that production costs averaged 14, 1, and 21% lower for corn, soybean, and fall cereals, respectively, with reduced input compared to conventional input management, and 38, 4, and 23% lower costs

Table 5. Effect of input management and crop diversity on total annual production costs (without all-risk crop insurance)

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	CV[1]
	($ ha^{-1})													%
High input														
Low crop diversity rotation	269	245	259	280	324	268	273	251	244	274	269	286	270	8
Diverse annual grains rotation	341	315	317	328	418	361	314	334	310	334	377	355	342	9
Grains and forage rotation	298	316	267	303	387	331	297	319	297	339	329	377	322	11
Mean (high input)	303	292	281	304	376	320	295	301	284	316	325	339	311	9
Reduced Input														
Low crop diversity rotation	264	232	255	269	297	286	265	289	244	256	306	262	269	8
Diverse annual grains rotation	314	278	313	313	409	363	302	353	310	328	362	348	333	11
Grains and forage rotation	300	279	267	311	359	311	373	354	329	326	348	372	327	11
Mean (reduced input)	293	263	278	298	355	320	313	332	294	303	339	327	310	9
Organic input														
Low crop diversity rotation	278	282	283	292	279	231	191	192	250	239	289	237	254	14
Diverse annual grains rotation	280	281	287	318	273	241	212	213	261	230	262	232	258	13
Grains and forage rotation	280	291	264	303	335	247	237	247	377	244	238	248	276	16
Mean (organic input)	279	285	278	304	296	240	213	217	296	238	263	239	262	12
Means (Low crop diversity rotation)	270	253	266	280	300	262	243	244	246	256	288	262	264	7
(Diverse annual grains rotation)	312	291	306	320	367	322	276	300	294	297	334	312	311	8
(Grains and forage rotation)	293	295	266	306	360	296	302	307	334	303	305	332	308	8
Input LSD (P<0.05)	ns	14***	ns	ns	21***	19***	23***	18***	ns	18***	21***	17***		
Diversity LSD (P<0.05)	16***	14***	17***	19***	21***	19***	23***	18***	17***	18***	21***	17***		
Input x Diversity LSD (P<0.05)	28*	24**	ns	ns	37***	34*	ns	ns	29***	31**	36***	30***		

[1] Coefficient of variation.

***, **, *, and ns refer to the significance of factors at 1%, 5%, 10%, and non-significant, respectively.

for the respective crops with organic management practices. In the USA, most studies of small grain production have also reported cost saving of up to 49% with organic compared to conventional and reduced tillage systems (Diebel et al. 1993; Delate et al. 2006; Archer et al. 2007).

Expenditures for seed were lowest for the HI/DLW treatment ($28 ha^{-1}) due to the high proportion of summer fallow included in this rotation, and were highest for the OI/DAG and OI/DLW treatments ($71 ha^{-1}) reflecting the reliance on legume green manure crops to build soil N fertility, together with the higher seeding rates and higher unit seed costs for the OI managed grain crops (Table 6). Seed costs for the RI treatments were intermediate between the HI and OI treatments, averaging about 33% more than for the HI treatments due to the higher seeding rates that were also used with the RI treatments in our study.

Expenditures on inorganic fertilizers, primarily N, were lowest for the DLW crop diversity treatments, reflecting the inclusion of summerfallow or legume green manure partial-fallow in these rotations (Table 6). Summerfallowing enhances N mineralization from soil organic matter, but frequent use of this practice, particularly when combined with mechanical tillage for control of weeds, mines the soil reducing soil organic matter and fertility levels in the long-term, plus it exposes the soil to other environmental damage from wind and water erosion, deep leaching of plant nutrients, and enhanced emissions of greenhouse gases (Acton and Gregorich 1995; Janzen et al. 1999). The higher fertilizer costs for RI compared to the respective HI treatments reflects that as soil tillage is reduced with conservation tillage management there is a build-up of crop residues on the soil surface which slows the rate of residue decomposition resulting in the temporary immobilization of N until the system reaches its new equilibrium (Unger and McCalla 1980). Others have also suggested that with no-till management there is greater risk of N loss by denitrification than in tilled systems, especially in wet years (Aulakh et al. 1982). Thus during this transition period, N availability is often lower under conservation tillage management resulting in somewhat higher N fertilizer recommendations based on soil tests

Table 6. Effect of input management and crop diversity on production costs by resource category (without all-risk crop insurance, 1996-2007)

Input level/Crop diversity	Seed	Fertilizer[1]	Pesticides	Labor	Operating interest	Other[2]	Fuel & Oil	Repairs	Machines & Buildings	Total
High input										
Low crop diversity rotation	27.61	46.69	28.34	13.45	5.63	26.57	31.11	23.14	67.71	270.25
Diverse annual grains rotation	36.41	72.72	44.94	14.43	7.16	26.57	31.76	24.41	83.65	342.05
Grains and forage rotation	41.71	62.69	27.64	14.90	6.56	26.57	31.81	24.43	85.27	321.58
Mean (high input)	35.24	60.70	33.64	14.26	6.45	26.57	31.56	23.99	78.88	311.29
Reduced Input										
Low crop diversity rotation	42.30	53.10	40.92	11.47	6.00	26.57	20.10	16.11	52.07	268.64
Diverse annual grains rotation	50.23	73.60	49.29	12.85	7.26	26.57	23.49	18.93	70.63	332.85
Grains and forage rotation	49.10	74.75	33.77	14.22	6.96	26.57	25.58	20.35	76.11	327.41
Mean (reduced input)	47.21	67.15	41.33	12.85	6.74	26.57	23.06	18.46	66.27	309.64
Organic input										
Low crop diversity rotation	69.87	0.00	0.00	13.02	5.03	31.51	32.59	24.50	77.10	253.62
Diverse annual grains rotation	71.07	0.00	0.00	13.20	5.09	31.51	33.03	24.92	78.75	257.57
Grains and forage rotation	65.31	13.69	0.00	14.23	5.30	31.51	31.49	24.57	89.85	275.95
Mean (organic input)	68.75	4.56	0.00	13.48	5.14	31.51	32.37	24.66	81.90	262.37
Means (Low crop diversity rotation)	46.59	33.26	23.09	12.65	5.55	28.22	27.93	21.25	65.63	264.17
(Diverse annual grains rotation)	52.57	48.77	31.41	13.49	6.50	28.22	29.43	22.75	77.68	310.82
(Grains and forage rotation)	52.04	50.38	20.47	14.45	6.27	28.22	29.63	23.12	83.74	308.31

[1] Includes compost which was applied to selected crops within the Reduced input/Grains and forage rotation and the Organic input/Grains and forage rotation.
[2] Includes land taxes, farm utility costs, plus certification and related fees for organic treatments.

compared to conventional tillage systems (McConkey et al. 1996; Zentner et al. 2002a). In the longer term, however, it is expected that this effect may diminish and could possibly reverse as the relative soil organic matter levels build over time with the continued use of conservation tillage management, particularly when combined with the periodic inclusion of a legume green manure or legume forage crops as in the DLW and DAP treatments (Campbell et al. 1996; Janzen et al. 1998).

Pesticide expenditures averaged \$8 ha^{-1} higher for RI than for HI treatments, with the cost difference being as large as \$13 ha^{-1} for the DLW cropping diversity treatment (Table 6). These trends reflect that with conservation tillage management herbicides were substituted for mechanical tillage in the control of weeds prior to planting and on summer fallow areas compared to the use of mechanical tillage alone. Other Canadian prairie studies comparing conventional and conservation tillage practices have reported a several fold increase in herbicide expenditures with zero tillage management in 2-yr or 3-yr cereal-fallow rotations due to the higher cost of controlling weeds on summer fallow areas with herbicides than with tillage (Zentner et al. 1992a, 1996b), but they too reported a much smaller increase in herbicide costs when using zero tillage management together with continuous crop rotations. This latter effect reflects the normally small difference in cost between one preseeding herbicide application to control weeds on zero-till stubble areas, compared to one, and in some years two, preseeding tillage operations to control weeds and to prepare the seedbed on stubble areas under conventional tillage management.

Although differences in labor costs among input treatments were not large, they tended to be lowest for RI, intermediate for OI, and highest for the HI treatments (Table 6). Further, labor costs tended to be lowest for the DLW and highest for the DAP cropping systems. However, these costs capture only the direct labor required to conduct field operations and perform other production activities and do not include labor associated with management aspects. Studies of conventional and organic systems in the USA often report higher direct labor requirements with organic systems (Karlen et al. 1995; Archer et al. 2007)) but also higher management labor input

due to the greater need to scout and inspect crops for emerging plant pest and nutrition problems, the increased time to research and devise non-chemical control strategies, and the greater effort and costs required to develop and secure markets for organic products (Hanson et al. 1997; Pimentel et al. 2005). Consequently, our labor cost values likely under-estimate the relative total labor requirements of the various cropping systems, particularly for the OI treatments, and this could become an important factor influencing producer's decisions to adopt organic practices, especially as farm size increases or if the operator has limited access to unpaid family labor or is dependent on off-farm employment (Hanson et al. 1997; Scheeberger et al. 2002; Pimentel et al. 2005).

Expenditures for fuel and machine repair were lowest for the RI treatments, and higher but generally similar for the HI and OI treatments (Table 6), consistent with findings of other comparative studies of conventional and conservation tillage management practices in western Canada (Smith et al. 1996; Zentner et al. 2002a, 2002b). In contrast, several USA studies have reported higher expenditures for fuel with organic compared to conventional practices due to the heavy reliance of organic management on mechanical tillage for weed control and seedbed preparation (Mahoney et al. 2003; Archer 2007). The savings in machine-related operating costs with conservation tillage management in our study arise from fewer trips across the field and from using machines with greater capacity and lower draft requirements (sprayer versus cultivator). Machine overhead costs were also lowest for the RI treatments, intermediate for HI, and highest for OI treatments. The savings in machine overhead costs with RI compared to HI arise from eliminating (or reducing) the need for tillage machines, using smaller sized power units with lower capital investment, and extending the life of machines because of their reduced annual use. Similarly, the higher machine overhead costs for the OI treatments reflects the greater use and reduced life of tillage equipment plus the need for additional and specialized machines (e.g., rotary hoe for in-crop weed control and manure spreader for compost application) used only with OI management.

Participation in the Canada/Saskatchewan all-risk crop insurance program (excluding insurance on legume green manure and forage crops) added \$10 to \$15 ha^{-1} to the total annual system costs for the DLW treatments shown in Table 5. It added \$14 to \$16 ha^{-1} to the total costs for the DAG treatments, and \$5 to \$6 ha^{-1} for the DAP treatments, with the respective OI cropping systems tending to have the higher total insurance premium costs.

Overall, the savings in labor plus machine related costs with RI versus HI management were largely offset by higher expenditures for seed, fertilizers and pesticides, as reported in earlier studies (Zentner et al. 2002a, 2002b). In contrast, the savings in expenditures for inorganic fertilizers and pesticides with OI management more than offset the higher costs for seed, organic certification and inspections, and machine overhead compared to the non-organic treatments.

Gross Returns

Gross returns or income earned from the sale of grain and forage (with full price premiums for organic products beginning in 1998) were highest for the cropping systems in 1999 and lowest in 2002 (Table 7), directly reflecting the growing conditions and resulting crop yields. Gross returns were significantly influenced by input level in 11 of the 12 study years. In 1996 and 1997 when the organic systems were still completing the 3-yr certification period, gross returns were highest for the HI and RI (1997 only) systems, but in 9 of the remaining 10 years, gross returns for the OI systems were equal or modestly higher than those from other input treatments. Overall, however, there was a relatively little difference in the 12-yr average gross returns among the methods of input management.

In contrast, gross returns were influenced by cropping diversity in all study years (Table 7), with the DAG systems typically providing the highest (in 8 of 12 years) and the DAP systems the lowest gross earnings. In the drought years, gross returns were generally highest for the DLW crop diversity treatments, reflecting the greater soil moisture reserves for crops grown on summer fallow versus on stubble land (Campbell et al. 1990). Gross returns averaged \$505

Table 7. Effect of input management and crop diversity on gross product sales (100% organic price premiums)

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	CV[1]
	($ ha^{-1})													%
High input														
Low crop diversity rotation	674	386	263	889	651	331	113	189	362	539	395	566	447	50
Diverse annual grains rotation	823	484	417	963	796	259	95	252	415	597	470	808	532	51
Grains and forage rotation	554	311	167	568	476	99	59	105	231	439	306	489	317	58
Mean (high input)	684	394	282	807	641	230	89	182	336	525	390	621	432	52
Reduced Input														
Low crop diversity rotation	578	422	363	720	637	331	104	185	362	436	395	557	424	42
Diverse annual grains rotation	747	502	450	906	851	298	97	218	371	518	478	744	515	49
Grains and forage rotation	458	314	276	480	426	109	73	102	198	394	310	466	301	50
Mean (reduced input)	594	413	363	702	638	246	91	168	310	449	394	589	413	46
Organic input														
Low crop diversity rotation	364	283	394	884	610	351	208	284	557	543	543	829	488	44
Diverse annual grains rotation	315	214	356	1033	614	332	201	287	571	494	440	762	468	52
Grains and forage rotation	294	239	267	635	414	153	85	148	410	500	407	666	352	53
Mean (organic input)	324	245	339	851	546	279	165	240	513	512	463	752	436	48
Means (Low crop diversity rotation)	539	364	340	831	633	338	142	219	427	506	444	651	453	43
(Diverse annual grains rotation)	628	400	408	967	754	296	131	252	452	536	463	771	505	48
(Grains and forage rotation)	435	288	237	561	439	120	72	118	280	444	341	540	323	51
Input LSD (P<0.05)	44***	48***	56**	32***	58**	ns	9***	33***	71***	42***	38***	36***		
Diversity LSD (P<0.05)	31***	21***	27***	32***	44***	25***	10***	20***	49***	27***	40***	40***		
Input x Diversity LSD (P<0.05)	62***	57***	67***	55*	85***	ns	17***	43*	ns	56***	68***	67***		

[1] Coefficient of variation.

***, **, *, and ns refer to the significance of factors at 1%, 5%, 10%, and non-significant, respectively.

ha^{-1} for the DAG systems, about 10% less for the DLW systems, and 36% less for the DAP systems. Thus overall, the HI/DAG and RI/DAG treatments produced the highest gross returns ($524 ha^{-1}), while the HI/DAP and RI/DAP treatments produced the lowest ($309 ha^{-1}).

As reported for total grain plus forage production, the variability in annual gross returns (as measured by CV) tended to be lower for RI compared to the HI and OI systems, reflecting the benefit of reducing tillage intensity for enhancing soil moisture conservation (Brandt 1992; McConkey et al. 1996). Similarly, the relative variability in annual gross returns tended to be lower for the DLW crop diversity treatments reflecting the value of including summer fallow or partial-fallow in the rotation to enhance soil moisture reserves, build soil N levels, and help control problem weeds compared to continuously cropped systems (Brandt and Zentner 1995; McConkey et al. 1996; Zentner et al. 1996a).

Net Returns

a) Base Grain and Forage Prices

Net returns (i.e., profit or residual income remaining after paying for all production costs) for the cropping systems, and without participation in the Canada/Saskatchewan all-risk crop insurance program, averaged $173 ha^{-1} for the OI treatments, $121 ha^{-1} (30% less) for HI, and $104 ha^{-1} (40% less) for the RI treatments (Table 8). The net earnings were significantly influenced by input level in 11 of 12 years, with economic losses common for most treatments during the drought years. In 1996 and 1997 when the OI treatments did not yet qualify for organic price premiums, net returns for these systems were substantially lower (and often negative) compared to the non-organic input treatments, and this reduced income during the certification/transition period is often reported as a major barrier to the adoption of organic practices by non-organic producers (Schneeberger et al. 2002; Smith et al. 2004). Since then, however, the OI treatments earned the highest net returns in 8 of the 10 subsequent years, and shared the top ranking with other input treatments in the other 2 years. Among the non-organic treatments, average net returns were higher for HI than the RI treatments in 4 years, lower in 2

Table 8. Effect of input management and crop diversity on net returns (100% organic price premiums and without all-risk crop insurance payouts)

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	SD[1]	NPV[2]
	($ ha^{-1})														
High input															
Low crop diversity rotation	405	141	4	609	327	63	-160	-62	119	265	126	280	176	213	1635
Diverse annual grains rotation	482	169	99	635	378	-102	-219	-82	105	263	93	453	190	260	1765
Grains and forage rotation	256	-4	-100	266	89	-231	-238	-214	-66	100	-23	112	-4	175	24
Mean (high input)	381	102	1	503	265	-90	-206	-119	53	209	65	282	121	213	1141
Reduced Input															
Low crop diversity rotation	315	191	108	452	340	46	-161	-104	118	180	89	295	156	180	1457
Diverse annual grains rotation	433	224	137	593	442	-65	-206	-135	61	190	116	396	182	249	1726
Grains and forage rotation	158	35	9	169	67	-202	-299	-252	-131	68	-38	94	-27	159	-165
Mean (reduced input)	302	150	85	405	283	-74	-222	-164	16	146	56	262	104	193	1007
Organic input															
Low crop diversity rotation	86	1	111	592	331	120	17	92	306	304	254	591	234	202	1950
Diverse annual grains rotation	36	-67	69	715	340	91	-11	74	310	264	177	530	211	233	1758
Grains and forage rotation	14	-52	3	332	78	-95	-152	-99	33	256	170	419	76	182	568
Mean (organic input)	45	-39	61	546	250	39	-49	22	216	275	200	513	173	199	1425
Means (Low crop diversity rotation)	269	111	74	551	333	76	-101	-25	181	250	156	389	189	182	1681
(Diverse annual grains rotation)	317	109	102	648	387	-25	-145	-48	159	239	129	460	194	228	1752
(Grains and forage rotation)	143	-7	-29	256	78	-176	-230	-188	-55	141	36	208	15	159	142
Input LSD (P<0.05)	42***	47***	53**	31***	ns	57***	8***	32***	69***	40***	36***	34***			
Diversity LSD (P<0.05)	30***	21***	26***	31***	43***	25***	10***	20***	48***	26***	39***	39***			
Input x Diversity LSD (P<0.05)	59***	55***	65***	54**	ns	66***	17***	ns	ns	54***	66**	64***			

[1] SD = standard deviation.

[2] Net present value computed using a discount rate of 5%.

***, **, *, and ns refer to the significance of factors at 1%, 5%, 10%, and non-significant, respectively.

years, and similar in 6 years. These latter results are generally similar to those reported in earlier studies comparing conservation and conventional tillage management of monoculture wheat and fallow-based cropping systems under western Canadian growing conditions (Smith et al. 1996; Zentner et al. 1996a; Zentner et al. 2002a). Further, our results suggest that the RI treatments, which also included use of a more integrated approach to pest and nutrient management problems, were generally less profitable than the HI treatments which used a more conventional approach of performing tillage operations and applying full recommended rates of pesticides and inorganic fertilizers as required. These latter findings differ from those reported by Smith et al. (2006) whom confirmed the economic merits of using integrated weed and nutrient management practices over conventional high-input practices for cereal-oilseed and cereal-pulse cropping systems in this region.

Net returns were also influenced by the cropping diversity treatments in all years, with the input by diversity interaction significant in 9 of these years (Table 8). Net returns averaged \$192 ha^{-1} for the DAG and DLW cropping systems, but only \$15 ha^{-1} (92% less) for DAP. The DLW systems had the highest net earnings (or lowest losses) in the drought years (2001 to 2003), while DAG had the highest net returns in 5 years (1996, 1998, 1999, 2000, and 2007). In the remaining 4 years there was no difference in the net returns for the DAG and DLW treatments. Net returns were lowest for the DAP treatments in all years, reflecting the low forage yields obtained in most years and the relatively low price for forage compared to grain crops, consistent with the general findings reported for conventional and organically managed grain and grain-forage rotations in southern Alberta (Smith et al. 2004) and with results from an earlier study of conventional mixed grain and grain-forage rotations at the Scott location (Zentner et al. 1996a). Overall, the most profitable treatment combination was DLW with OI management (average \$234 ha^{-1}). This was followed closely by DAG with OI management (about 10% less than the best system), and then by the DAG systems with HI and RI input (about 21% less). The least profitable cropping system was DAP with RI input with an average net loss of \$27 ha^{-1}.

The rankings of treatments were largely unchanged when based on the 12-yr net present values, which incorporate the time value of money (Table 8). The OI/DLW system ranked highest in terms of net present value, followed by the three DAG treatments with values that averaged about 10% less than for the best system. The length of time required for the OI treatments to break even with the non-organic systems (i.e., years required to provide equal accumulated net returns) was about 6 years after organic certification was completed for the DLW rotation (i.e., in year 2003), 7 years for the DAG rotation (year 2004), and 5 years for the DAP rotation (year 2002). By comparison, in southern Alberta, Smith et al. (2004) reported that the time required to break even compared to the respective conventional rotations under the most likely organic price premium scenario was 8 years for a 2-yr wheat-legume green manure rotation, 1 year for the 4-yr wheat-pulse-oilseed-legume green manure rotation, but the organically managed 4-yr mixed grain-forage rotation would never break even with the comparable conventionally managed rotation. Further, they reported that average net returns under this same price scenario were highest and generally similar for the organically managed wheat-pulse-oilseed-legume green manure rotation and for conventional continuous wheat. The organically managed 2-yr wheat-legume green manure rotation ranked second highest, and was significantly more profitable than the conventional 2-yr wheat-fallow rotation. The organic and conventional mixed grain-forage rotations produced economic losses, as was also found in our study. Most USA studies have also reported similar or higher net earnings with cropping systems that use organic versus conventional management; however, the relative profitability depended on whether transition costs from conventional to organic management practices, price premiums for organic products, and unpaid family labor were included in the calculations (Hanson et al. 1997; Mahoney et al. 2004; Pimentel et al. 2005; Delate et al. 2006; Archer et al. 2007).

Year-to-year variability in net returns (as indicated by CV averaged over crop diversity treatments) in our study was lowest for the OI systems (CV = 115%), compared to a CV of 176% for HI and 186% for RI. Similarly, net income variability was lowest for the DLW systems (CV

= 96%), compared to a CV of 118% for DAG, and a CV of over 1000% for DAP due largely to the low mean net return values for the DAP treatments. The lower income variability for the DLW systems reflects the advantage of fallow-based rotations in stabilizing net farm income compared to continuously cropped systems in this water-constrained region (Zentner and Campbell 1988; Zentner et al. 1992a).

Participation in the Canada/Saskatchewan all-risk crop insurance program increased the annual net returns for the treatments by an average of \$21 ha^{-1} (range of \$10 to \$37 ha^{-1}), with the increases tending to be larger for the DAG systems (Table 9). The DLW treatments received significant payouts from the program in 3 to 4 years compared with 4 to 5 years with the DAP treatments, and 6 to 7 years with DAG. However the overall rankings of the treatments based on the mean annual net returns and net present values changed relatively little compared to the no crop insurance situation. The main impact from participation in the all-risk crop insurance program was to reduce the frequency and magnitude of the economic losses, particularly in the drier years, which helped reduce the year-to-year variability in net returns. For example, the CV values for the OI treatments (meaned across crop diversity levels) declined by about 25 percentages points with participation in the program compared to a decline of about 52 percentage points for the HI and RI treatments. Similarly, the decline in CV values with participation in the program (meaned across input levels) was about 24 percentage points for the DLW treatments, 35 for DAG, and over 500 percentage points for the DAP treatments. The lower net income variability with all-risk crop insurance reduces the overall riskiness of the cropping systems, a benefit to producers who are risk averse (Zentner and Campbell 1988).

Our findings with respect to participation in the all-risk crop insurance program may over-state the impact on net returns for the cropping systems. For example, in our analysis, crop yield guarantees were held constant throughout the 12-yr study period as were the annual insurance premium costs for crops (Table 4). However, producers who are on operating on an individual farm coverage basis would have their yield guarantee levels for crops adjusted

Table 9. Effect of input management and crop diversity on net returns (100% organic price premiums and with all-risk crop insurance payouts)

Input level/Crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	SD[1]	NPV[2]
	($ ha^{-1})														
High input															
Low crop diversity rotation	395	136	48	599	317	77	-59	12	128	255	120	270	192	184	1765
Diverse annual grains rotation	473	180	132	621	367	-19	-60	5	128	264	100	437	219	215	2019
Grains and forage rotation	251	-4	-56	261	84	-177	-176	-159	-47	95	-22	107	13	151	178
Mean (high input)	373	104	41	494	256	-40	-98	-47	70	205	66	271	141	181	1321
Reduced Input															
Low crop diversity rotation	306	184	105	441	330	55	-59	-29	122	174	82	285	166	151	1542
Diverse annual grains rotation	420	225	150	579	427	2	-49	-36	94	203	127	380	210	203	1958
Grains and forage rotation	152	32	13	164	77	-158	-246	-192	-104	67	-37	89	-12	136	-40
Mean (reduced input)	293	147	89	395	278	-34	-118	-86	37	148	57	251	122	161	1152
Organic input															
Low crop diversity rotation	73	-8	137	579	318	178	194	213	312	351	241	575	264	179	2199
Diverse annual grains rotation	33	-57	109	701	366	143	157	178	314	333	183	517	248	211	2078
Grains and forage rotation	10	-58	-1	327	73	-71	-87	-58	40	282	164	413	86	171	653
Mean (organic input)	39	-41	82	536	252	83	88	111	222	322	196	502	199	179	1644
Means (Low crop diversity rotation)	258	104	97	540	322	103	25	65	187	260	148	377	207	150	1836
(Diverse annual grains rotation)	309	116	130	634	387	42	16	49	179	267	137	445	226	188	2020
(Grains and forage rotation)	138	-10	-15	251	78	-135	-170	-136	-37	148	35	203	29	138	264
Input LSD (P<0.05)	44***	37***	30**	30***	ns	33***	4***	22***	58***	39***	31***	35***			
Diversity LSD (P<0.05)	28***	18***	18***	31***	41***	13***	5***	11***	44***	24***	34***	38***			
Input x Diversity LSD (P<0.05)	59***	44***	39***	53**	ns	38***	8***	27***	ns	52***	57**	64***			

[1] SD = standard deviation.

[2] Net present value computed using a discount rate of 5%.

***, **, *, and ns refer to the significance of factors at 1%, 5%, 10%, and non-significant, respectively.

annually based on their historical 10-year moving average yields. At the same time, their annual insurance premium costs would be adjusted based on these coverage levels and their past record of claims. Nevertheless, our findings serve to illustrate the relative benefits of all-risk crop insurance in protecting against significant net income declines (or losses) in drought years and in helping to reduce the overall riskiness associated with adopting new or alternative cropping systems.

b) Effect of Changes in Grain and Forage Prices

A reduction of 25% in the price for grain and forage crops from the base levels (Table 3) (input costs held constant) resulted in much larger proportional declines in net returns for the cropping systems (Figure 1). For example, average annual net returns (meaned over crop diversity levels) declined by \$122 ha^{-1} (or 61%) for the OI treatments, \$116 ha^{-1} (or 91%) for RI, and \$110 ha^{-1} (or 82%) for the HI treatments in response to the 25% reduction in crop prices. Similarly, when meaned over input levels, annual net returns declined by an average of \$138 ha^{-1} (or 61%) for DAG, \$121 ha^{-1} (or 58%) for DLW, and \$89 ha^{-1} (over 300%) for DAP. At these lower crop prices, the DAG and DLW treatments remained profitable, but the DAP treatments experienced large economic losses. However, the overall rankings of the cropping systems were little changed by the reduction in grain and forage prices. The most profitable treatment at the 25% price reduction level was OI/DLW; this was followed by OI/DAG, and then by HI/DAG, RI/DAG and HI/DLW (Figure 1). The least profitable treatments were as before HI/DAP and RI/DAP.

A 25% increase the price for grain and forage crops increased annual net returns for the treatments by similar amounts as for the 25% price reduction situation, but this too tended to have little impact on the overall rankings of the cropping systems (Figure 1).

In contrast, changes in the price premiums received for organic products had a major impact on net returns and the overall rankings of the OI treatments (Figure 2). For example, when the organic price premiums were reduced by 25% from current levels, average annual net

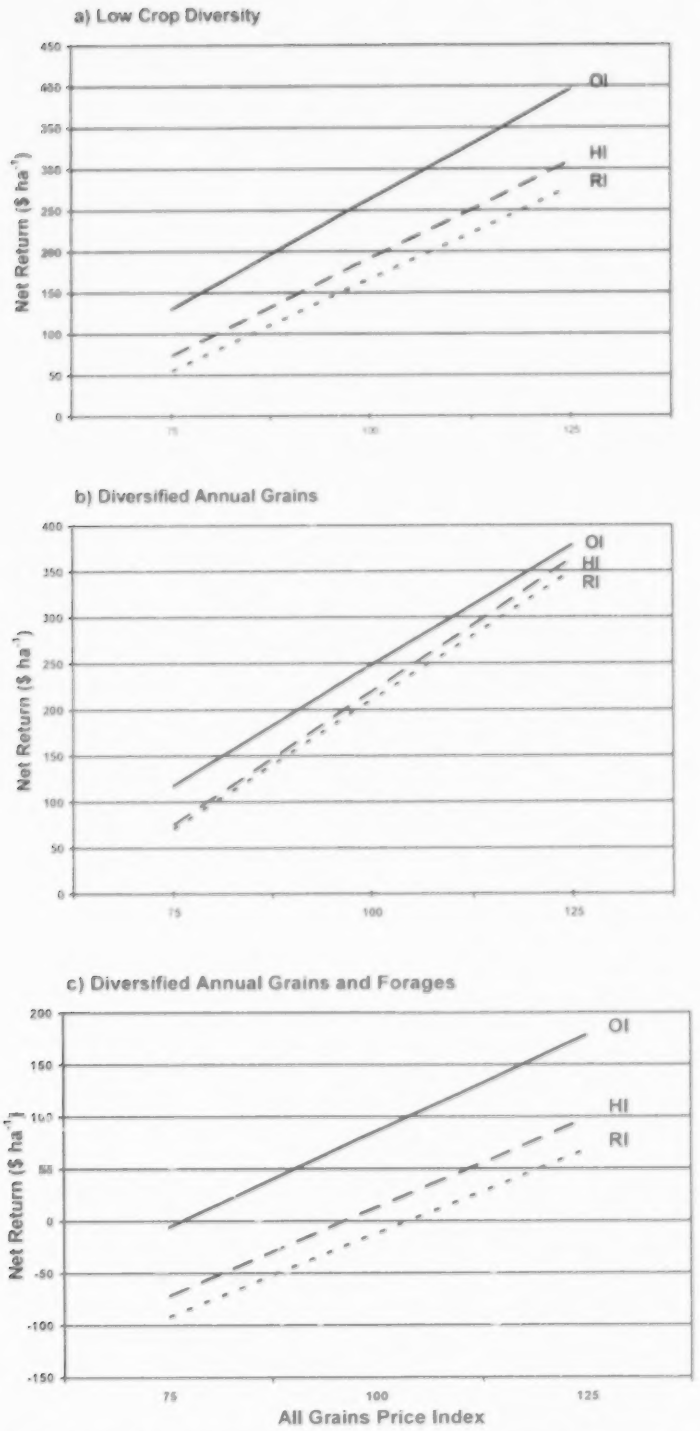

Figure 1. Effect of changes in crop prices on mean net returns of cropping systems, with all-risk crop insurance (1996-2007).

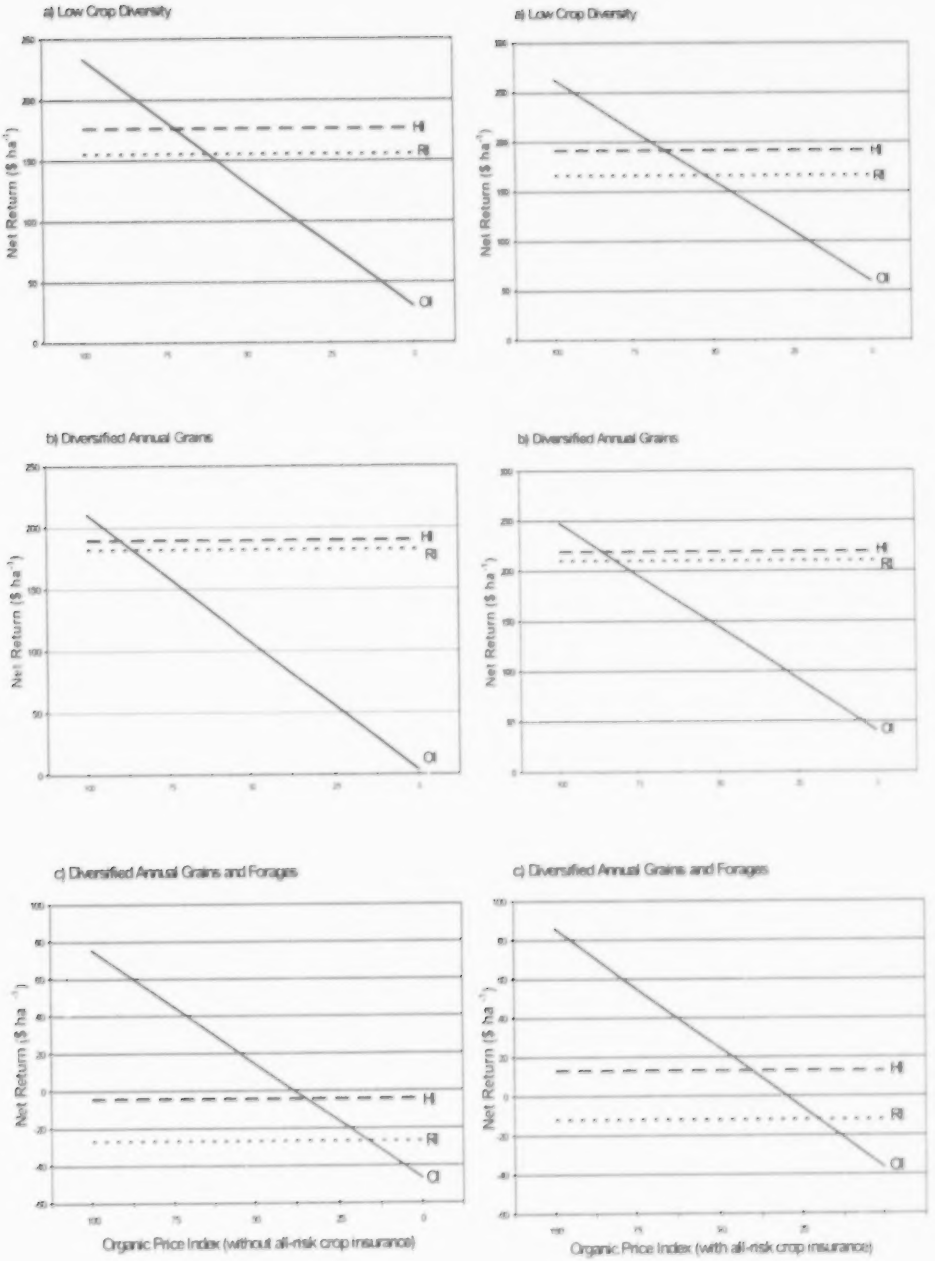

Figure 2. Effect of changes in organic price premiums on mean net returns of cropping systems, without and with all-risk crop insurance (1996-2007).

returns for the OI managed DLW, DAG, and DAP treatments declined by \$51, \$52, and \$31 ha^{-1}, respectively. Similarly, at no price premiums for organic products, net returns for the respective OI treatments declined by \$204, \$208, and \$122 ha^{-1}, making them the least profitable cropping systems. As reported earlier, at full prices premiums for organic crops, the OI treatments were significantly more profitable than the respective HI and RI treatments, with the OI/DLW system being most profitable. However, when the organic price premiums were reduced to less than about 70% of the base values, HI/DAG replaced OI/DLW as the overall most profitable cropping system.

Within the DLW treatments, reductions in the organic price premiums of up to 30% without all-risk crop insurance, and reductions of up to 35% with all-risk crop insurance, could be tolerated before the profitability of the OI/DLW system declined below that of HI/DLW (i.e., the best non-organic system within this crop diversity level) (Figure 2). In contrast, within the DAG treatments, the organic price premiums could only decline by about 8% without all-risk crop insurance and by about 13% with all-risk crop insurance, before HI/DAG and RI/DAG replaced OI/DAG as the most profitable treatments. Likewise within the DAP treatments, the organic price premiums could decline by as much as 60 to 65% before OI/DAP became less profitable than HI/DAP. These differences in threshold values among crop diversity levels reflect the relative profitability of the respective organic and non-organic treatments. For example, when the difference in net returns between an organic and non-organic treatment is initially positive and large (as in the case for the DLW and DAP), the organic treatment can accommodate a much larger reduction in the organic price premiums (and resulting net returns) before its profitability level and rank order fall below that of the non-organic treatment, compared to when the difference in net returns between treatments is small (as in the case of DAG). This dependency of the OI treatments on price premiums raises a concern about the long-term economic viability of organic practices as more producers convert from conventional to organic production methods, particularly if the demand for organic products does not keep pace with rising supplies.

These results are in general agreement with those of Smith et al. (2004) who reported that the relative profitability of the organic cropping systems in southern Alberta were highly conditional upon the existence of sizable and sustained organic prices premiums. Several USA studies have also reported similar findings (Batte et al. 1993; Mahoney et al. 2003; Archer et al. 2007); but, others report that organic production practices can be equally or more profitable than conventional practices even without price premiums for organic products (Hanson et al. 1997; Welsh 1999).

c) Effect of Changes in Fuel and Fertilizer Costs

Changes in the cost of on-farm fuel use (holding other input cost and product prices constant at the base levels), although influencing the magnitude of net returns earned, and having the greatest impact on the HI and OI systems, had little effect on the overall rankings of the treatments (Figure 3). With a 50% increase in the cost of farm fuels, annual net returns declined by \$16 to \$17 ha^{-1} for the HI and OI treatments, and by \$10 to \$13 ha^{-1} for the RI treatments due to their lower fuel requirements. A decrease of 50% in the cost of fuel had the opposite effects. However, over the range of fuel costs considered in our analysis, the rank order of the treatments was largely unchanged.

Changes in the cost of inorganic fertilizers influenced net returns only for the non-organic treatments (Figure 4). With a 50% increase in the cost of N and P fertilizers, average net returns declined by about \$26 ha^{-1} for the HI/DLW and RI/DLW treatments, \$38 ha^{-1} for the HI/DAG and RI/DAG, and \$32 ha^{-1} for the HI/DAP and RI/DAP treatments, increasing the relative differential in net returns between the organic and non-organic treatments. A 50% decrease in the cost of fertilizers had the opposite effect on average net returns for the treatments, improving the relative profitability of the non-organic compared to the organic systems. In the case of the DAG cropping systems, the 50% decline in fertilizer costs produced net earnings for the respective HI and RI treatments that were similar to OI/DAG, and only about \$12 ha^{-1} less than for the best overall cropping system. But for much of the range in fertilizer costs examined, the top ranking

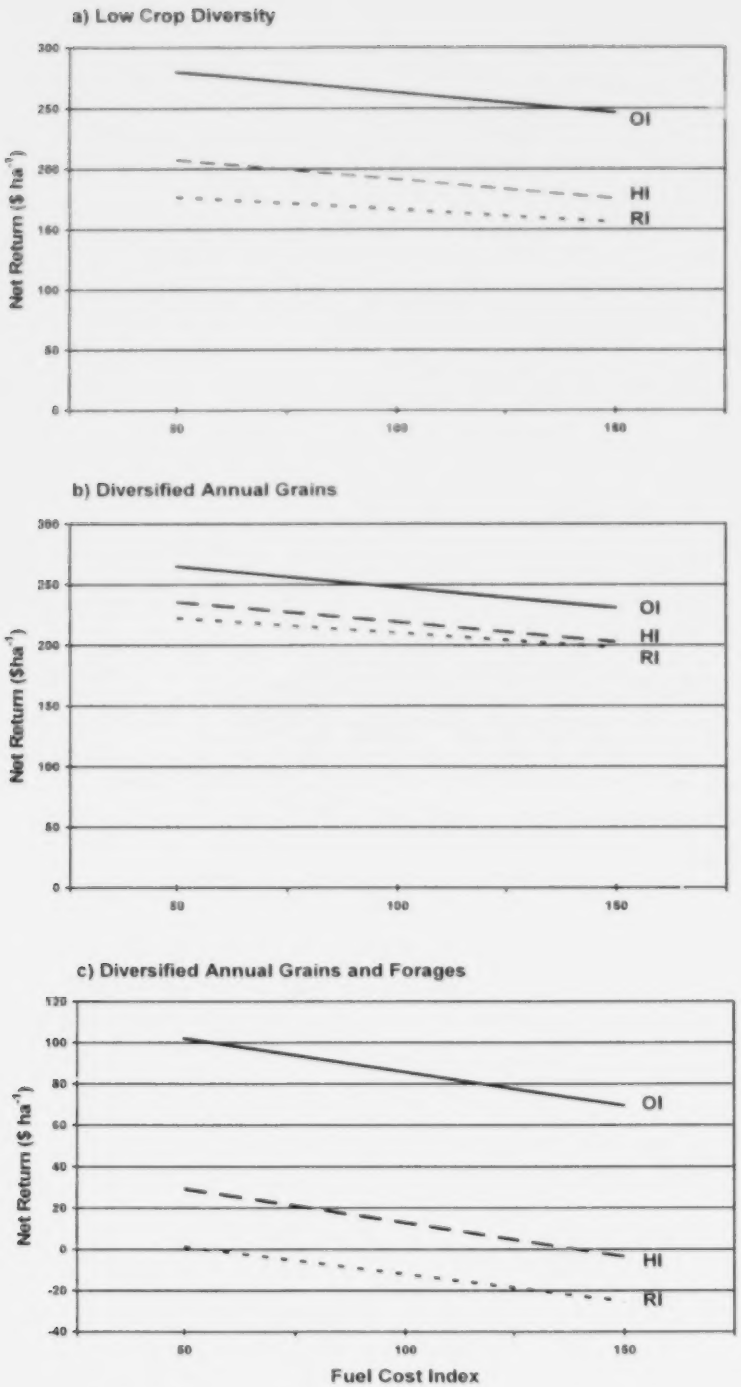

Figure 3. Effect of changes in fuel costs on mean net returns for cropping systems, with all risk crop insurance (1996-2007)

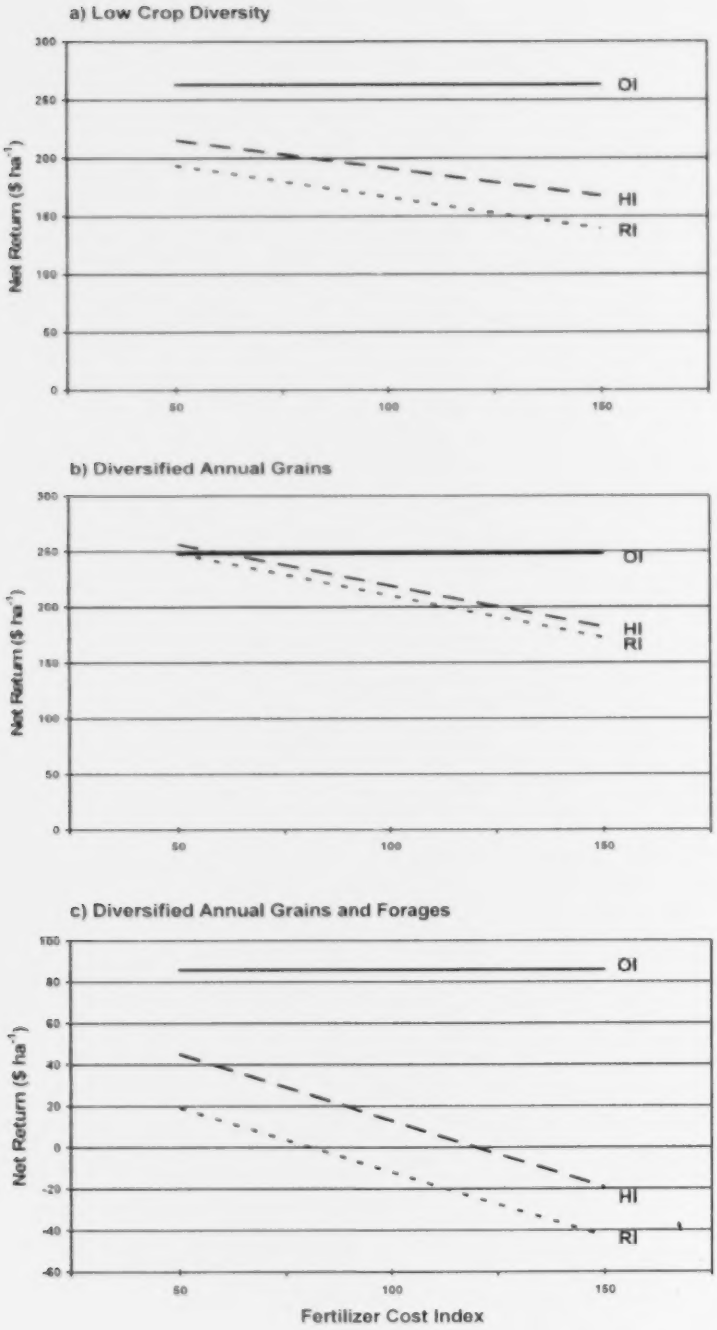

Figure 4. Effect of changes in inorganic fertilizer costs on mean net returns of cropping systems (1996-2007)

cropping system (OI/DLW) was unchanged from the base situation.

Riskiness of Cropping Systems

Decision making in risky situations, as in choosing among cropping systems, often requires making a trade-off between the potential to earn higher net returns on one hand and having to accept a higher level of income variability on the other hand (Zentner et al. 2002b). The amount of income variability or risk that producers are willing to accept depends on their personal preferences, attitudes towards risk, and financial situation (Anderson et al. 1977). Producers who are less willing to gamble will often forego production opportunities that offer significant increases in net return but higher income variability for those that offer lower net returns but also lower risk.

Based on comparisons of the cumulative probability density functions of net returns among all treatments using stochastic dominance principles (Goh et al. 1989), risk averse producers would typically choose only the OI/DLW cropping system when crop prices were at the base levels and without the protection of all-risk crop insurance (Table10). Under this same crop price scenario but with participation in the all-risk crop insurance program, producers who are more willing to accept some risk would also consider choosing the more intensively cropped OI/DAG treatment. These findings differ from those reported in Alberta by Smith et al. (2004) who determined that the organic treatments had slightly higher financial risk than the conventionally managed rotations. In contrast, in southwestern Minnesota Mahoney et al. (2004) did not find net returns to be more variable or risky with organic production methods, while Hanson et al. (1990) reported that in southeastern Pennsylvania an organic cash grain rotation was preferred by risk averse producers over a conventional corn-soybean rotation.

When comparisons of the probability distributions were made only among the non-organic treatments, producers with low risk aversion and who participate in all-risk crop insurance would choose either HI/DAG or RI/DAG, while those who do not subscribe to all-risk crop insurance would choose HI/DAG or HI/DLW (Table 10). Non-organic producers with

Table 10. Risk efficient cropping systems[1] for selected crop price, input cost, and all-risk crop insurance scenarios

Crop price/Input cost	All-risk crop insurance	Level of risk aversion		
		Low	Medium	High
i) Base crop prices				
All treatments[2]	No	OI/DLW	OI/DLW	OI/DLW
	Yes	OI/DLW; OI/DAG	OI/DLW; OI/DAG	OI/DLW
Non-organic treatments only[3]	No	HI/DAG; HI/DLW	HI/DLW	HI/DLW
	Yes	HI/DAG; HI/DLW; RI/DAG	HI/DAG; HI/DLW	HI/DLW
ii) 25% decrease in all crop prices				
All treatments	Yes	OI/DLW	OI/DLW	OI/DLW
Non-organic treatments only	Yes	HI/DLW	HI/DLW	HI/DLW
iii) 25% increase in all crop prices				
All treatments	Yes	OI/DLW; OI/DAG; HI/DAG	OI/DLW; OI/DAG; RI/DAG	OI/DLW; OI/DAG; RI/DAG
Non-organic treatments only	Yes	HI/DAG; RI/DAG	HI/DAG; RI/DAG; HI/DLW	HI/DAG; HI/DLW
iv) 25% decline in organic crop prices				
All treatments	Yes	OI/DLW; HI/DAG; RI/DAG	OI/DLW; HI/DLW	OI/DLW; HI/DLW
v) 50% decline in organic crop prices				
All treatments	Yes	HI/DAG; HI/DLW; RI/DAG	HI/DAG; HI/DLW	HI/DLW
vi) 50% decline in fertilizer costs				
All treatments	Yes	OI/DLW; OI/DAG; HI/DAG	OI/DLW; OI/DAG; HI/DAG	OI/DLW; HI/DAG; RI/DAG
vii) 50% increase in fuel costs				
All treatments	Yes	OI/DLW; OI/DAG; RI/DAG	OI/DLW; OI/DAG; RI/DLW; RI/DAG	OI/DLW; RI/DLW

[1] HI = high input, RI = reduced input, and OI = organic input, while DLW = low diversity and intensity of annual grains; DAG = diversified using annual grains; and DAP = diversified using annual grains and perennial forages.

[2] Comparisons of the cumulative probability distributions of net returns were completed among all cropping treatments.

3 Comparisons of the cumulative probability distributions of net returns were completed among the non-organic treatments only.

medium risk aversion would also choose HI/DAG or HI/DLW, while those who are even more risk averse would choose only the HI/DLW system with its high proportion of summer fallow. Historically, frequent of summerfallowing has been the main management practice used by producers in semiarid regions to stabilize crop yields and farm income (Campbell et al. 1990). These findings are in general agreement with those reported in earlier studies of conventionally managed cropping systems in the study area (Zentner and Campbell 1988; Zentner et al. 1992a).

When grain and forage prices were reduced by 25% from the base levels, the risk efficient cropping systems were unchanged, except when the non-organic treatments were considered by themselves in which case only the HI/DLW system would be selected by risk averse producers (Table 10). In contrast, when crop prices were increased, the risk efficient set included the more intensively cropped DAG systems. The willingness of risk averse producers to choose more intensively cropped systems as crop prices increase reflects in part the higher total annual production values that are normally forthcoming with continuously cropped systems (and thus higher relative net returns) compared to fallow-based cropping systems (Part I, Table 6) (Zentner and Campbell 1988).

When the price premiums for organic products were reduced by 25% (holding conventional crop prices and input costs at base levels), HI/DAG and RI/DAG were included along with OI/DLW as the preferred cropping systems by producers with low risk aversion, while HI/DLW and OI/DLW were preferred by medium and high risk averse producers. When organic price premiums were reduced by 50% or more, the organic systems were no longer risk efficient or preferred by producers. Reductions in the cost of fertilizers and fuels also encouraged producers with low and medium risk aversion to choose among the diversified annual grains systems, while highly risk averse producers would tend to choose the cropping systems that included summer fallow. The DAP systems, with their low annual net returns and high relative income variability would not be chosen by risk averse producers under any of the economic scenarios examined.

CONCLUSIONS

This study examined the economic performance of 9 cropping systems, consisting of 3 methods of input management and 3 levels of cropping diversity, for the Dark Brown soil zone of Saskatchewan. The input management methods included: high input (HI), which used conventional tillage and the full recommended rates of fertilizers and pesticides as required; reduced input (RI), which used conservation tillage and integrated weed and nutrient management practices; and organic input (OI), which used tillage, non-chemical pest control, higher seeding rates, delayed seeding, and legume crops to replenish soil nutrients. The crop diversity treatments included a fallow-based rotation with low crop diversity (DLW), a diversified rotation using cereal, oilseed and pulse grains (DAG), and a diversified rotation using annual grains and perennial forages (DAP). All crop rotations were 6 years in length. The analysis was conducted over the 1996-2007 period during which growing season precipitation was below normal in 8 of the 12 years.

Under 2007 input cost levels and prices for conventional and organically grown crops, our findings support the growing interest by area producers in adopting alternative land use practices. The most profitable cropping system, with the current organic price premiums of 30 to 80% over conventional crop prices, was OI/DLW. This was followed closely by OI/DAG (10% less), and then by HI/DAG and RI/DAG (21% less) (the best non-organic systems). The mixed grain-forage rotations were not economically competitive with the grain-only treatments under all methods of input management. The organic treatments had consistently lower production costs (16% less) compared to the non-organic treatments, with the savings in expenditures for inorganic fertilizers and pesticides with organic management more than offsetting the higher costs for seed, organic certification and inspection fees, and machine overhead. While the OI treatments had direct labor requirements that were comparable to HI treatments, but greater than for RI, the requirement for management labor is believed to be greater with organic management. Producers using organic practices may need to spend more time scouting and inspecting crops for emerging

pest problems and in securing markets for their products compared to producers using non-organic practices. Thus the potentially higher total labor requirement may become an important constraint to adopting organic practices as farm size increases, or if the operator has limited access to unpaid family labor or has off-farm employment.

Net returns for the organic systems were much lower and often negative during the certification period compared to the non-organic treatments. Our results indicated that it took from 5 to 7 years beyond completion of the certification period for the OI treatments to recoup this foregone income. Thereafter, the OI systems were consistently more profitable than the non-organic systems. This reduced income during the transition from conventional to organic management may create cash-flow and loan re-payment challenges for some producers with limited access to credit or those who may need to make adjustments or additions to their machine inventories to accommodate organic practices. The relative profitability of the organic systems was also highly dependent on the existence significant price premiums for the organic products. When the organic price premiums were reduced to less than 70% of current levels, the organic treatments were less profitable than the non-organic treatments. This calls into question the long-term economic viability of the organic management practices as more producers move to organic management unless demand for organic products keeps pace with the increasing supply, or if producers find other ways to add additional value to their products (e.g., packaging and selling products in smaller quantities versus in bulk, or processing raw crops into finished food products).

Among the non-organic treatments, net returns were highest for HI/DAG and RI/DAG, with net returns averaging about 11% less for the DLW systems. Despite higher production costs for DAG compared to DLW systems, our findings did not indicate any significant savings in total costs with using RI versus HI management. Although expenditures for labor, fuel, repairs, and machine overhead were lower with the use of conservation tillage and integrated nutrient and pest management practices, these savings were largely offset by increased expenditures for seed,

fertilizers, and herbicides compared to HI management.

From a risk management perspective, the organic systems displayed lower income variability than the non-organic systems, with the OI/DLW cropping system being preferred by risk averse producers. Participation in the Canada/Saskatchewan crop insurance program was effective in reducing the risk associated with adopting the more intensive and diversified cropping systems, with the OI/DAG treatment also becoming a member of the risk efficient set for producers with lower risk aversion. However, the high proportions of legume green manure partial-fallow included in these rotations, combined with the heavy reliance on mechanical tillage, suggests that the soil may become exposed to erosion losses, thus negating the benefits of the soil-building legume green manure crops, unless caution is exercised by producers. Among the non-organic treatments, producers with low risk aversion and who subscribe to all-risk crop insurance would choose the HI/DAG or RI/DAG systems, while those with moderate risk aversion would choose HI/DAG or HI/DLW, and those with high risk aversion would choose HI/DLW. The preference for the conventional HI/DLW cropping system by medium and high risk averse producers in our study also carries the potential concern for increased soil erosion compared to the more intensive cropping systems or those that use conservation tillage practices.

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